MAY 12 '52

Volume 22 MARCH, 1952 Number 1

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

« CONTENTS »

Deep ripple marks in the sea ..... *Henry W. Menard* 3
Adaptation of the piston coring device to shallow water sampling... ..... *Maxwell Silverman and Richard C. Whaley* 11
Clastic quartz particles as indices of provenance ..... *John Bokman* 17
Relation of surface angle distribution to particle size distribution on alluvial fans ..... *Erich Blissenbach* 25
Possible utilization of electrophoretic phenomenon for separation of fine sediments into grades ..... *George Tchillingarian* 29
SYMPOSIUM ON MICROBIOLOGY IN RELATION TO THE GEOLOGIC ACCUMULATION OF ORGANIC COMPLEXES 33
Degradation of plant tissues in organic sediments .... *Elso S. Barghoorn* 34
Part played by bacteria in petroleum formation.. *Claude E. Zobell* 42
DISCUSSION
Loess, an eolian product ..... *D. J. Doeglas* 50
Reply to the remarks of N. M. Shukri on "Beach sands of the Mediterranean coast of Egypt" ..... *Mohamed E. Hilmy* 53
REVIEW
Philip B. King. The Tectonics of Middle North America .... *J. V. Harrison* 54
ANNOUNCEMENTS
Cordilleran Section of the Geological Society of America Meeting 56
Guidebook for the Forty-Eighth Meeting, Cordilleran Section G. S. A. 57

Journal of Sedimentary Petrology

J. L. HOUGH, EDITOR
University of Illinois
Urbana, Illinois

ASSOCIATE EDITORS

W. C. KRUMBEIN
Northwestern University
Evanston, Illinois

K. O. EMERY
University of Southern California
Los Angeles, California

RALPH E. GRIM
University of Illinois
Urbana, Illinois

R. DANA RUSSELL
U. S. Navy Electronics Laboratory
University of California
San Diego, California

ADVERTISING MANAGER
THOMAS H. PHILPOTT
Box 1739
Shreveport, Louisiana

The *Journal of Sedimentary Petrology* is published by the Society of Economic Paleontologists and Mineralogists, a division of The American Association of Petroleum Geologists. Numbers are issued in March, June, September and December.

The subscription price of the *Journal of Sedimentary Petrology* is $5.00 per year prepaid to addresses in the United States.

Single numbers, $1.75 each ($1.35 to members).

Postage is charged extra for all other countries: 40 cents on annual subscriptions (total $5.40).

The *Journal* will furnish reprints at cost. Orders should accompany corrected galley proof.

Communications about *Journal* subscriptions, rates, memberships, change of address, and non-receipt of preceding number should be addressed to Society of Economic Paleontologists and Mineralogists, P.O. Box 979, Tulsa, Oklahoma. Claims for non-receipt of preceding numbers must be sent in within three months of the date of publication in order to be filled gratis.

Communications in regard to manuscripts and purely editorial matters should be addressed to J. L. Hough, Journal of Sedimentary Petrology, University of Illinois, Urbana, Illinois.

Communications in regard to advertising should be addressed to Thomas H. Philpott, Box 1739, Shreveport, Louisiana.

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN

PRINTED IN THE U.S.A.

Volume 22 MARCH, 1952 Number 1

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

CONTENTS

Deep ripple marks in the sea ..... *Henry W. Menard* 3
Adaptation of the piston coring device to shallow water sampling ..... *Maxwell Silverman and Richard C. Whaley* 11
Clastic quartz particles as indices of provenance ..... *John Bokman* 17
Relation of surface angle distribution to particle size distribution on alluvial fans ..... *Erich Blissenbach* 25
Possible utilization of electrophoretic phenomenon for separation of fine sediments into grades ..... *George Tchillingarian* 29
SYMPOSIUM ON MICROBIOLOGY IN RELATION TO THE GEOLOGIC ACCUMULATION OF ORGANIC COMPLEXES 33
Degradation of plant tissues in organic sediments ..... *Elso S. Barghoorn* 34
Part played by bacteria in petroleum formation ..... *Claude E. Zobell* 42
DISCUSSION
Loess, an eolian product ..... *D. J. Doeglas* 50
Reply to the remarks of N. M. Shukri on "Beach sands of the Mediterranean coast of Egypt" ..... *Mohamed E. Hilmy* 53
REVIEW
Philip B. King. The Tectonics of Middle North America ..... *J. V. Harrison* 54
ANNOUNCEMENTS
Cordilleran Section of the Geological Society of America Meeting. 56
Guidebook for the Forty-Eighth Meeting, Cordilleran Section G. S. A. 57

NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal*, should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

Among papers to appear in forthcoming issues of the *Journal* are the following:

Symposium on Microbiology in Relation to the Geological Accumulation of Organic Complexes (continued).

Turbidity currents, graded and non-graded deposits. By Ph. H. Kuenen and Henry W. Menard.

Analcime in the Pogo Agie member of the Chugwater formation. By W. D. Keller.

Submarine geology of Cortes and Tanner Banks. By J. E. Holzman.

Measures for describing the size distribution of sediments. By Douglas L. Inman.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 3–9
PLATES 1, 2, FIG. 1, MARCH, 1952

DEEP RIPPLE MARKS IN THE SEA

HENRY W. MENARD
U. S. Navy Electronics Laboratory, San Diego, California

ABSTRACT

Submarine photography reveals that ripple marks are common in deep water in the sea. Current ripple marks have been found at a depth of 792 feet, and ripple marks which appear to be due to oscillation have been found at 4,500 feet. Water movement competent to move sediment must extend to these depths.

INTRODUCTION

Water-formed ripple marks are among the most common of the original surface features preserved on the bedding planes of sedimentary rocks. The environmental significance of ripple marks has been studied extensively, both because ripple marks are so common, and because they obviously provide some clues regarding the currents or waves that produced them, and the seas, rivers, or lakes in which they were formed. Special interest may be attached to the maximum depth at which modern ripples are formed in the sea, because other sedimentary processes must extend down to this same depth and also because ripple marks in sedimentary rocks have been taken as an indication of shallow water.

In 1841, Siau observed that the sea floor near the island of Reunion was covered with ripples with coarse grains in the hollows and fine grains on the crests. By lowering a sounding lead with wax on the bottom he was able to prove that alternate bands of coarse and fine material continued out to a depth of 617 feet (Johnson, 1919, p. 489). This figure has remained in the geological literature for more than one hundred years as the maximum depth at which ripples have been observed. In the past four years, however, the expanding development and use of submarine photography has revealed that ripples are common in water several hundred feet deep, and that they exist in water several thousand feet deep.

Ripple marks appear on 46 of 111 relatively clear photographs taken in depths greater than 300 feet by the Navy Electronics Laboratory; but the significance of these numbers is small. A "relatively clear" photograph is taken to be one on which something can be identified; this introduces a bias toward a high number of photographs of ripple marks because the marks are distinguishable on some hazy photographs, whereas a flat bottom may just appear as a blur, and blurred photographs are not counted because the blur may be suspended sediment that conceals the bottom. On the other hand, most of the photographs were taken in places where the bottom is rocky in an attempt to study the rocks. Random photography, therefore, might show a higher percentage of ripple marks. Moreover, as many as 38 relatively clear photographs have been taken in one place, and only one photograph in another. Perhaps the number of areas where ripple marks have been photographed is more significant; 8 of 10 areas show ripples.

ACKNOWLEDGMENTS

Most of the unpublished photographs tabulated and discussed in this paper were taken by Carl Shipek of the U. S. Navy Electronics Laboratory.

K. O. Emery, O. F. Evans, Ph. H. Kuenen, F. P. Shepard, H. C. Stetson and members of the Navy Electronics Laboratory have read the manuscript and made suggestions which have been incorporated into the final draft. Professor Stetson was also kind enough to loan

TABLE 1.—*Locations, depths, and symmetry of ripple marks.*

Depth in Feet	Symmetry	Location
246	?	Tanner Bank, California Borderland
200–300	symmetrical	Santa Rosa Ridge, California Borderland
300	asymmetrical	South entrance to Unimak Pass, Aleutian Islands
348	?	Cortez Bank, California Borderland
420	?	Ranger Bank, Baja California (Emery, 1948)
468	?	Coronado Ridge, California Borderland
498	asymmetrical	Gulf of Maine (Ewing, Vine, and Worzel, 1946)
625	asymmetrical	Slope off town of San Clemente, California
720	asymmetrical	Nodales Channel, British Columbia
792	asymmetrical(?)	Forty Mile Bank, California Borderland
1650	symmetrical(?)	"Fieberling" Bank, 530 miles west of San Diego, California
4500	symmetrical(?)	Sylvania Guyot, northern Marshall Islands (Plate 1)
4500	symmetrical(?)	Sylvania Guyot, northern Marshall Islands (Plate 2)

several sea floor photographs taken during recent Woods Hole Oceanographic Institution investigations.

LOCATION AND DEPTH OF RIPPLES

The locations, depths, and symmetry of some submarine ripple marks are summarized in table 1. The shoaler ones are included in the table in order to indicate the number of places in which they have been photographed. Not all of the ripple marks can be identified as to type or even as to symmetry. Many photographs are clouded by turbid water; and, even in the best photographs, the two dimensional plan view with a point source of lighting tends to obscure the shape of some features. Moreover, the origin of ripple marks is not always determinable even in the most favorable conditions for observation on land. The ripple marks called "symmetrical" would not be termed so by a geometrician, but they appear to be as symmetrical as most "symmetrical," wave-formed, ripple marks in shallow water. Ayrton (1910) and more recently Evans (1941) have noted the widespread occurrence of slightly asymmetrical wave-formed ripple marks. A summary of observations by members of the Scripps Institution of Oceanography and the Navy Electronics Laboratory permits the generalizations that at a given time, individual ripple marks may be symmetrical in one place and asymmetrical 10–15 feet away, and that at a given place, individual ripple marks may be symmetrical at one time, and asymmetrical a few minutes later. Symmetrical ripple marks are produced by alternating currents of equal intensity generated by waves. Waves in still water produce symmetrical ripple marks, but waves in the ocean usually are superimposed on independent or related mass transport of the water. Unless the waves are at right angles to the current, the wave-produced alternating current with a component in the direction of the mass transport is reinforced, and the opposed alternating current is retarded. Ripple marks produced in such circumstances are more or less asymmetrical depending on the relative velocity of mass transport and the velocity of the alternating currents. Because of the gradations between oscillation and current ripple marks, identification of any but the end members must be arbitrary. For the present purposes, current ripple marks are considered to be those that are strongly asymmetrical and that have one slope at the angle of repose, and the other more or less convex upward. Approximately symmetrical ripple marks with two slopes concave upward are considered to be produced by oscillatory water movement. Many photographs show oriented

PLATE 1.—Ripple marks at a depth of 4,500 feet on Sylvania Seamount. See figure 1 for a profile of these ripple marks. The distance between ripple marks in the center of the photograph is about 12 inches.

scours or shells which give more indication of the type of water movement than do the ripple marks.

The deepest ripple marks which definitely were produced by a current have been photographed in Nodales Channel, British Columbia, at a depth of 720 feet. Elsewhere in this channel, current ripple marks have been photographed at 420 feet and 618 feet. In the two shoaler photographs, numerous ophiuroids are oriented by the current; one leg points up-current, two legs are perpendicular to the current and their tips curve down-current, the other two legs form a "V" which opens down-current. Many of the legs pointing up-current are obscured, and appear to be buried in the sand to form an anchor. The most striking evidence for rapid current ripple mark move-

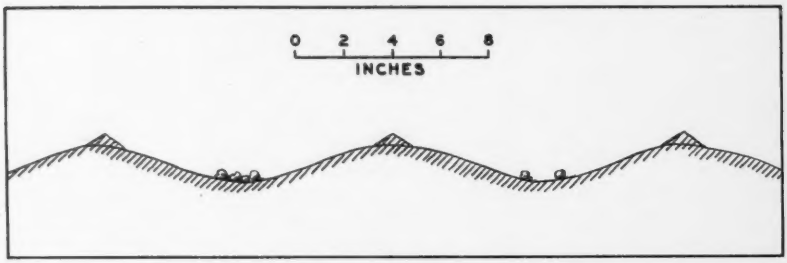

FIG. 1.—Profile of ripple marks on Sylvania Seamount (plate 1).

ment in deep water appears in three photographs taken at the southern approach to Unimak Pass, Aleutian Islands, at a depth of 300 feet. In these photographs, current ripple marks have moved over ophiuroids that are partially buried by the ripple mark ridges but exposed in the hollows between ridges.

The ripple marks on Sylvania Guyot (pls. 1 and 2) were at a depth of 4500 feet. The wavelength of the ripples shown in plate 1 is about 12 inches; the amplitude is about 3 inches. The writer's impression of the profile of the ripple marks in plate 1 appears in figure 1. This profile was made from the two-dimensional photograph by viewing two copies of the photograph with a stereoscope. The image seen through the stereoscope is not actually three dimensional, but the illusion of three dimensions is very strong and reliable. War-time photo interpreters often took advantage of this illusion when stereoscopic photographs were not available. The horizontal scale of the photographs and the profile has been calculated from the focal length of the camera, the distance from the lens to the sea floor, and the dimensions of the negative. The vertical dimensions shown in figure 1 have been computed from the length of the shadows in the central part of plate 1. These ripple marks are thought to have been produced by oscillatory water movement—rather than a steady current—for the following reasons:

1. They appear to be approximately symmetrical in profile.

2. The profile shows a series of rounded undulations with superimposed angular crests. Ripple marks with profiles of this type are caused by waves, according to Evans (1949). The writer has watched waves form ripple marks of this shape at Sippowisset, Massachusetts. The angular crest of relatively unconsolidated sand migrates back and forth over the rounded crest of the underlying relatively consolidated ripple mark. Two times of formation of ripple marks are indicated.

3. According to Evans' criteria (1949) for distinguishing current ripple marks from asymmetrical oscillation ripple marks, the ripple marks between rocks (pl. 2) are even more suggestive. (The criteria apply equally well to ripple marks which probably are symmetrical, but Evans reasonably assumed that it is always possible to determine the symmetry of ripple marks.)

   a. The edges of the ripple marks lap over the adjacent rocks. Currents probably would sweep them off the rocks.
   b. The ripple marks are relatively straight between the rocks. Current ripple marks would be convex downcurrent due to fluid drag on the rocks.

It may be worthwhile to reconstruct the history of the sediment photographed in plate 2. Individual tests of pelagic foraminifera settled onto a hard surface of cobbles and rock covered with a layer of manganese dioxide. The unconsoldated layer of foraminiferal sand then became

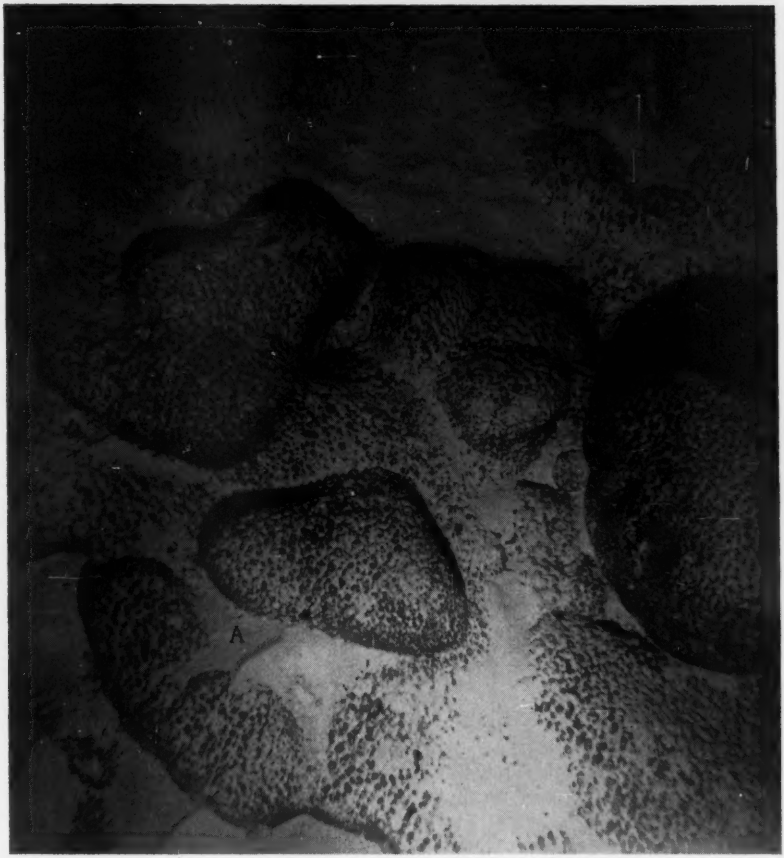

PLATE 2.—Ripple marks at a depth of 4,500 feet on Sylvania Seamount. Ripple marks are relatively straight between rocks and lap over the edges of the rocks. The base of the photograph is about 5½ feet wide, and the top is about 8 feet wide. Arrows show ends of ripple marks. "A" is an exposed area of ripple marked sand.

rippled by some type of water movement. If the movement had been due to a unidirectional current, flume experiments show that the sand would have formed barchan shaped ripple marks and migrated down current. As the ripple marks migrated they would reach relatively protected zones in the lee of cobbles, and there they would remain as "tails" pointing down current from the cobbles. This has not happened. Instead, the sand has been swept into patches, some in exposed positions, and ripple marks have formed on the patches ("A" in pl. 2). Such sweeping into patches with little regard for the irregularities on the bed is characteristic of oscillatory water movement.

The ripple marks photographed at a depth of 1650 feet on "Fieberling" Bank were formed on small patches of sand

between rocks. All the evidence for oscillatory movement shown in plate 2 at Sylvania Guyot applies to these ripple marks as well.

ORIGIN OF DEEP RIPPLE MARKS IN THE OCEAN

The current which formed the ripple marks at a depth of 720 feet in Nodales Channel, British Columbia probably was produced by tidal action. The channel is long and narrow, and open at both ends. The tidal velocity is as high as two knots. Mixing due to tidal action produces homogeneous water down to the bottom (Saur, 1950), and tidal velocities probably are appreciable at the bottom of the channel. Fast tidal currents move through deeper confined channels elsewhere in the world, and it appears likely that the floors of these channels are covered with ripple marks unless scouring has exposed bed rock.

The origin of the short period oscillations which produced the ripple marks on Sylvania Guyot and "Fieberling" Bank is not certain. Currents associated with wind-generated surface waves are confined to shallow depths. Long period waves such as the tides and seismic sea waves (tsunamis) would produce current ripples. It is possible that the oscillations were generated by internal waves, which are formed far below the ocean surface. Regardless of their origin, oscillatory currents need not be very fast in order to produce the ripple marks. The ripple-marked sediment is a globigerina ooze, and the largest foraminifera tests present in any significant quantity probably have a diameter of about one half a millimeter. In a hydraulic flume, a mean current velocity of about 24 cms/sec. is competent to move well-sorted quartz grains with a diameter of 0.5 mm; currents competent to move sand grains are also competent to form ripple marks (Menard, 1950) However, well sorted coarse grains require a far faster competent velocity than similar grains that form only a small percentage of a poorly-sorted sediment with a median finer than the coarse grains. The difference in competent velocity for a given sediment can be measured accurately only by experiments, and none have been made with the globigerina ooze, but some flume tests with quartz sands indicate that the competent velocity of a similar quartz "sand" probably is less than 20 cms/sec. In addition, competent velocity is proportional to $\sqrt{d_t - d_w}$ where d_t is the bulk density of the test plus the water contained in the test, and d_w is the density of the water surrounding the test. Consequently hollow tests are easier to move than solid quartz grains. Ten 0.5 mm foraminifera tests from a sample dredged near Sylvania Seamount had an average weight of about 0.1 mg, which indicates that the velocity required to move the tests probably is only about six-tenths of the competent velocity of a quartz sand with a similar size distribution.

CONCLUSION

Submarine photography has shown that ripple marks exist in the ocean far below the maximum depth of 617 feet quoted in geological literature. Current ripple marks have been found at a depth of 792 feet in Nodales Channel, probably as a result of the strong tidal currents confined in the narrow channel. Ripple marks at a depth of 4500 feet on Sylvania Guyot appear to be of the type produced by oscillatory water movement. The origin of short period oscillations at this depth is not known.

With regard to paleogeography and paleoecology, these observations indicate that ripple-marked marine sediments may be deposited in water almost a mile deep. No relationship between the wavelength of the ripples and depth has been observed. As to geological theories of submarine processes, submarine ripple marks are formed only by such currents and oscillations as are competent to

move sediment. These currents and oscillations must be capable of the same types of transportation and sorting of sediment that they produce in shallow water, although the processes may be much less intense in deep water.

REFERENCES

EMERY, K. O., *1948*. Submarine geology of Ranger Bank, Mexico: *Am. Assoc. Petroleum Geologists Bull.*, vol. 32, pp. 790–806.

EVANS, O. F., *1944*. Criteria for distinguishing between asymmetrical wave-formed ripple marks and current-formed ripple marks: *Oklahoma Acad. Sci. Proc.*, vol. 24, p. 87.

———, *1949*. Ripple marks as an aid in determining depositional environment and rock sequence: *Jour. Sedimentary Petrology*, vol. 19, pp. 82–86.

EWING, M., VINE, A., and WORZEL, J. L., *1946*. Photography of the ocean bottom: *Jour. Optical Soc. Am.*, vol. 36, pp. 307–321.

JOHNSON, D. W., *1919*. *Shore processes and shoreline development:* John Wiley and Sons, New York, 584 pp.

MENARD, H. W., *1950*. Sediment movement in relation to current velocity: *Jour. Sedimentary Petrology*, vol. 20, pp. 148–160.

SAUR, J. F. T., *1950*. Oceanographic features of Nodales Channel with application to underwater sound: U. S. Navy Electronics Laboratory, Rept. 188, 21 pp.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 11–16
FIGS. 1–4, MARCH, 1952

ADAPTATION OF THE PISTON CORING DEVICE TO SHALLOW WATER SAMPLING[1]

MAXWELL SILVERMAN AND RICHARD C. WHALEY
Chesapeake Bay Institute of The Johns Hopkins University

ABSTRACT

A piston core sampler was adapted for use in shallow water. Nearly 300 cores were taken in the Chesapeake Bay area, the majority of which were in sandy or gravelly sediments. These cores ranged in length from six inches to twenty feet with an average sand core length of six feet and the longest sand-gravel core fifteen feet. The apparatus consists of an upper assembly containing lead drive weights, a coring tube, a reducing coupling, piston, tool steel cutting edge, and a release mechanism modified after that of Hvorslev and Stetson. A rapid method of operation is described which has been found to work efficiently under favorable weather conditions. The length of sand and gravel cores recovered appears to depend upon grain size, water content, and wall friction.

INTRODUCTION

Developments in the use of the piston core sampler in the past six years indicated that certain modifications could be adopted to permit rapid and efficient use in shallow water. Therefore the Chesapeake Bay Institute under contract with the Office of Naval Research and in cooperation with the U. S. Navy Hydrographic Office and the U. S. Coast and Geodetic Survey constructed a shallow-water type sampler for use in the 1951 field season.

The original model of this particular device was used by Hough, in 1950, to secure a 37-foot core in 924 feet of water in Lake Micigan. The rig modified at the Chesapeake Bay Institute[2] was used to obtain nearly 300 cores in lower Chesapeake Bay and on the adjoining Continental Shelf. The cores ranged in length from six inches to twenty feet and were taken in mud, sand and gravel with the last two being the predominant materials cored. Water depths ranged from twenty to one hundred twenty-five feet. The maximum coring tube length used in any operation was twenty feet.

The sampler is given a high entrance velocity into the bottom by means of a free-fall release mechanism modified after Hvorslev and Stetson (1946). The cores are obtained by means of a piston which is immobilized as soon as the sampler touches bottom, thereby allowing the tube to fall down around it developing and maintaining a partial vacuum above the advancing core. Although greater pressure differentials are obtained in deep water use of this device, it has been observed that the differential in shallow water is still sufficient to overcome the wall friction produced by sandy and gravelly cores.

RIG ASSEMBLY

Essentially this sampler consists of an upper assembly of 2 1/2-inch pipe upon which are mounted the lead drive weights; the coring tube of 2-inch I.D., 2 1/4-inch O.D. seamless steel; a reducing coupling to join the above together; a piston; a tool steel cutting edge; and a

[1] Contribution from the Chesapeake Bay Institute, No. 5.

[2] Many individuals were instrumental in developing the design and use of this device. In particular the authors respectfully acknowledge the contributions of Dr. Jack L. Hough, University of Illinois; Drs. Maurice Ewing and J. Lamar Worzel, Columbia University; Mr. William Asher, The Johns Hopkins University; Commander W. F. Malnate, U.S.C. & G. S.; Mr. D. W. Booth, Chesapeake Bay Institute; Mr. Joseph F. Schreiber, Jr., University of Utah; Boatswain Grant Lewis, U.S.C. & G.S.; Chief Boatswains Mate Bruno Konieczka, U.S.C.G.

release mechanism which allows the coring tube to fall down around the piston during the operation (fig. 1).

Since strains of up to ten times the weight of the entire assembly have been registered in pulling the sampler out of certain types of bottom, the entire design was based upon this value. The boom or A-frame for handling the gear over the side, the winch, and the 3/8-inch stainless steel hoisting cable all have a six-ton load limit, allowing a consistent safety factor of better than 1 to 5. Because impact loads may double bending and shearing stresses in the coring tube as the sampler enters the bottom, the reducing coupling was designed to minimize the effects of these loads. For instance, under Euler's column analogy (Seely, 1947) a load of 9600 lb. must develop to cause bending in a sampler embedded ten feet in the bottom.

The upper assembly of the sampler is constructed of 2 1/2-inch heavy galvanized pipe with a welded flange at the lower end to hold the lead drive weights and a long bail at the upper end into which the release mechanism is hooked. The reducing coupling is constructed of tool steel and has a piston stop in its interior which bears the entire load of the sampler as it is retrieved from the bottom. Accordingly, this member has been lengthened to effect uniform stress distribution. Two types of couplings have been used, one with and one without water exit ports, with no significant difference in the results being observed.

The coring tubes are made of seamless steel tubing, 2-inch I.D., 2 1/4-inch O.D., with one inch of NF-16-2 threads (National Fine Series Machine Thread; 16 threads per inch; class 2 fit) at both ends. They have been used in 5-, 10-, and 20-foot lengths. The piston also is constructed of tool steel and has a diameter 1/64-inch less than the inside diameter of the coring tube. Effective pressure is maintained by the use of standard 2-inch piston cup leathers which adjust themselves to fit the .007-inch inside tolerance of the tube.

To prevent kinking of the cable, the piston is connected to a tool-steel swivel which in turn is bolted to an Electroline-type fiege fitting in which the hoisting cable terminates. This fitting is deemed far superior to zinced or babbited cable fittings because of the ease and simplicity of replacing fittings.

The cutting edges are made of unhardened tool steel and have a .05-inch reduction in inside diameter or choke to help overcome the effects of wall friction. Case hardening was proved unsatisfactory because of the resultant brittleness. Inside the cutting edge is placed a core catcher or orange peel valve of heavy spring copper (Emery and Dietz, 1941) on a brass ring. This has the effect of retaining coarse material and clayey material.

The release mechanism is essentially similar to that of Hvorslev and Stetson except for a long cable clamp welded to the side of the release. This modification enables the cable to be continuous from the winch to the piston. Through bolts are carried through the mechanism and are welded to the side opposite the clamp.

The counterweight, which is secured to the long arm of the release mechanism by a light line, is a streamlined lead weight. The weight used depends upon the pay-out speed of the winch. A weight of 65 pounds has been used with a fast winch and a 30 pound sounding lead with a slow winch. The lead drive weights used on the upper assembly are cast in 50 pound doughnuts. The standard weight used has been 250 pounds.

As in every oceanographic instrument corrosion is an ever present problem. The outside walls of the coring tubes and the coupling are periodically coated with red lead and the inside walls of the tubes are covered with a light machine oil. Naturally, some of this is retained on the core and allowances must be made for it during examination. On the other hand, the oil tends to reduce the inside wall friction. When not in use the cutting edges and piston are coated with a heavy grease.

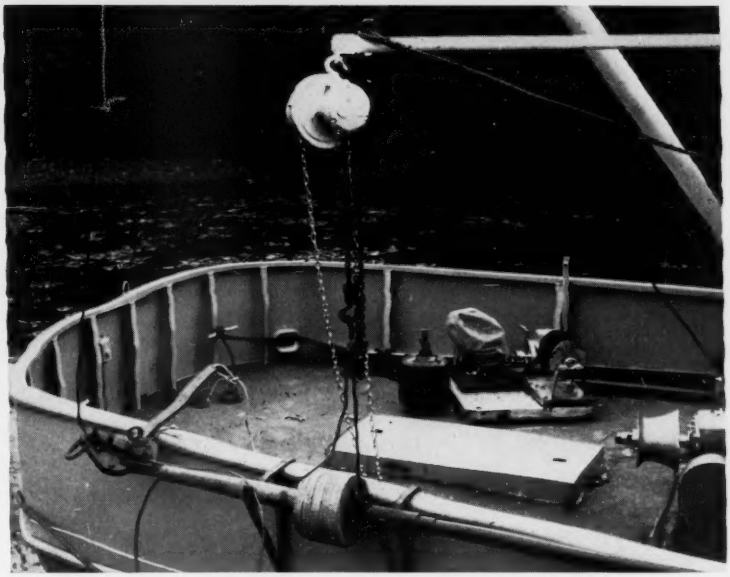

FIG. 2.—Rig assembled in rail-brackets showing release mechanism clamped to upper assembly and cable clamped to release with free-fall-loop hanging free.

METHOD OF USE

A complete coring operation with this sampler, including the rigging and dropping of the device, as well as the extrusion and packaging of the core, takes from ten to thirty minutes thus allowing a large number of cores to be taken in any one day.

In rigging the sampler the first operation consists of securing the upper assembly in brackets alongside the ship and threading on a section of tubing, the length of which is previously determined by a grab sample and the depth. In shallow water operation it may be necessary to limit the length of tubing used, in order to provide for complete submersion of the sampler. The cable is then run through and the swivel and piston bolted on to the fiege fitting. The piston is then pushed back about 3 inches from the lower end of the tube and the spring core catcher and cutting edge affixed.

At this point the release mechanism is clamped to the cable above the upper assembly and a loop of wire, equal to the amount of free fall desired, is allowed to hang free (fig. 2). Six- and eighteen-foot free falls have been used in the Chesapeake Bay operations. The release is then locked into place in the bail on the upper assembly and the counterweight and line secured to the long arm of the release. The length of this line corresponds to the length of the entire sampler plus the length of free fall used.

With everything secure and a safety pin in place on the release the rig is hoisted to a vertical position by means of a chain hoist suspended from either an auxiliary boom or from the A-frame (fig. 3). The safety pin is removed and the device is lowered into the water. On the moment of contact with the bottom, as indicated by slack in the line or on a dynamometer, the winch is immediately

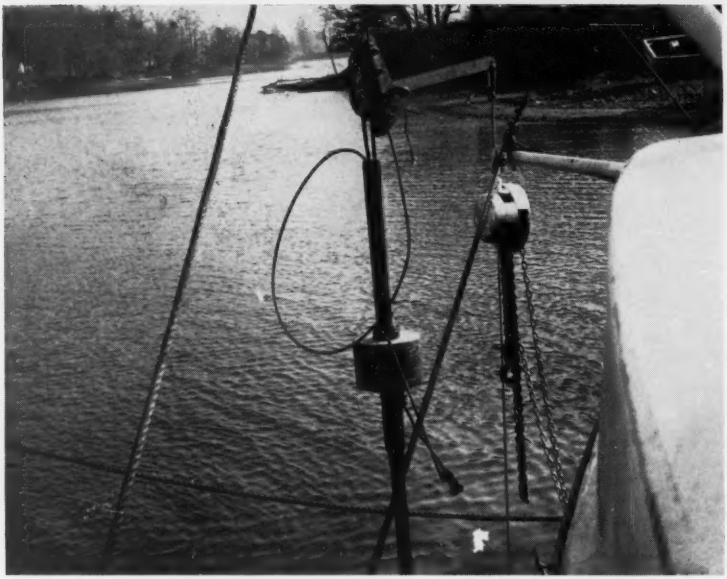

FIG. 3.—Rig suspended vertically from main boom ready to be lowered into the water.

braked to immoblize the piston at the bottom. The upward movement of the release arm, caused by the counterweight striking bottom, frees the sampler from the release mechanism and allows it to penetrate the bottom. When it is evident that downward motion of the tube has ceased the device is hauled to the surface, brought to a horizontal position by means of the chain hoist and the coring tube is removed.

During the operations in the Chesapeake Bay area, the cores were extruded immediately into a trough on deck and packaged in heavy water proof paper. It was observed that if the cores were allowed to remain in the tubes for any length of time extrusion became a very difficult process. Because of the present techniques of manual shipboard extrusion some distortion in length and water content of sand cores is to be expected. The extremely high wall friction of sand and gravel cores causes them to act quite differently from mud cores under the application of localized pressure.

Perhaps the most important consideration in efficient operation in shallow water is the presence of favorable weather conditions. Clear days are necessary if visual control is to be utilized. Coring can be safely accomplished in a choppy sea provided the crew is well trained. However, the presence of swell will inhibit coring operations. An irregular rise and fall of the ship as succeeding crests and troughs of a swell system pass it are sufficient to cause the device to trip above the bottom. At times a number of casts are necessary to obtain a core when swell is running at a station. The percentage of successful recoveries will thus decrease in rougher weather.

RESULTS

Over ninety percent of the coring stations occupied during the 1951 field season were on hard or sandy bottom.

FIG. 4.—Extruded core of sand and gravel 8′ long. Lower portion of core is gravel.

Here core lengths ranged from six inches to fifteen feet with the average length at six feet. At those stations on which a muddy bottom was encountered the maximum recovery was achieved nearly every time. In using a 20-foot tube, 20-foot recoveries were the result.

The sand cores ranged in grain size from very fine sand and silt through coarse gravel (fig. 4) and exhibited sorting from excellent to poor. Shelly material of all sizes was also recovered.

Two factors apparently influenced the length of sand core recovery. The first was grain size. The longest cores recovered were composed of moderately clean coarse sands and gravels. The shortest cores were composed of fine and very fine cohesionless sands which evidently poured out through the cutting edge leaving a slumped and distorted mass behind. The occurrence of clay size material in a core section, however, increased appreciably the amount of core retrieved.

The second factor, water content, was indicated by the greater lengths of supersaturated or water logged sand and gravel cores. The longest sand core obtained during this field season, fifteen feet, showed evidences of being part of an artesian system on the west side of Chesapeake Bay. A line of cores eastward across the Bay and away from the area in ques-

tion showed progressively shorter lengths as the water content of the cores decreased. A relatively dry sand from the east side of the Bay was three feet long upon extrusion.

Acutually the friction of the sand and gravel along the walls of the coring tube controls recovery. As long as the pressure differential above the core is greater than wall friction, the core will advance into the tube. When wall friction is greater than pressure further relative movement of the piston will merely draw water through the sands to form a water cap above the core.

CONCLUSIONS

The adaptation of the piston coring device just described has proved itself to be efficient under conditions of rapid use, shallow depths, and sandy bottom. Future modifications should deal with the problems of retaining fine grained cohesionless sands, of fast and undistorted extrusion, and of the use of a piston within a thin-walled liner.

REFERENCES

EMERY, K. O. and DIETZ, R. S., *1941*. Gravity coring instrument and mechanics of sediment coring: *Geol. Soc. America Bull.*, vol. 52, pp. 1685–1714.

HVORSLEV, M. JUUL, *1940*. The present status of the art of obtaining undisturbed samples of soils: *Harvard Univ. Publ. Grad. School of Eng., Soil Mech. Series* no. 14.

——— and STETSON, H. C., *1946*. Free-fall coring tube; a new type gravity bottom sampler: *Geol. Soc. America Bull.*, vol. 57, pp. 935–950.

KULLENBERG, B., *1947*. The piston core sampler: *Svenska Hydrografisk Biologiska Kommissionens Skrifter*, Bd. 1, Hafte 2.

SEELY, FRED B., *1947*. *Resistance of Materials*, John Wiley & Sons, New York.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 17–24
FIGS. 1, 2, MARCH, 1952

CLASTIC QUARTZ PARTICLES AS INDICES OF PROVENANCE

JOHN BOKMAN
The California Company, Ardmore, Oklahoma

ABSTRACT

Previous work on the use of detrital quartz as an index to provenance is critically examined, and it is concluded that the only two valid criteria advanced are 1) composite nature of polygranular fragments, and 2) shape of monogranular particles. The present study develops the second criterion, an attempt being made to group grains as either igneous or metamorphic solely on the basis of shape. Measurement of elongations (long axis/short axis) of several thousand quartz grains from sandstones of each of two formations revealed a statistical difference in the grain shapes of the two sandstones. Grains from several badly weathered crystalline rocks were also measured, and it was found that the average elongation for the grains of a granite was less than that for the grains of a schist. By analogy, it is concluded that the grain shape difference between the two sandstones is due to their derivation from different source rocks.

INTRODUCTION

This investigation was undertaken in conjunction with a more general petrologic study of the sandstones of the Stanley and Jackfork formations of the Ouachita Mountains, and the results were utilized therein. Early in the study it was suspected that the two formations had been derived from different sources, and an attempt was made to verify the idea by an analysis of the clastic quartz of the sandstones. The results of the investigation established the utility of quartz as a tool for provenance studies and substantiated the original surmise.

PREVIOUS WORK

Quartz is the chief detrital constituent of most sandstones, ranging from as low as 40 per cent in some arkoses and graywackes to nearly 100 per cent in pure orthoquartzites. Detrital quartz also constitutes a considerable proportion of many shales and clastic limestones. Due to the monotonous uniformity of its appearance, it does not seem promising as a tool for provenance studies. Several workers, however, have considered the problem of tracing sediments to their ultimate sources by a critical examination and analysis of the constituent quartz grains. Particular attention has been paid to the character of the extinction and the nature of the inclusions.

Mackie (1896), the first investigator in the field, divided the quartz grains of the sands and sandstones of Eastern Moray into four groups on the basis of their inclusions or lack thereof:

> Regular-inclusioned—included crystals are quartz, chlorite, muscovite, biotite, rutile, apatite, zircon, garnet, and magnetite.
>
> Acicular-inclusioned—inclusions are fine and needle-like; fine dark lines run in all directions through the grain, mineralogy unknown; sheaf-like aggregates of sillimanite; probably also apatite and tourmaline.
>
> Irregular-inclusioned—inclusions are almost always fluid lacunae with or without gas bubbles; sometimes arranged in parallel rows.
>
> Inclusionless.

He further states that,

> "... acicular and irregular inclusions preeminently abound in the quartz of granite. That the regular group is to be found in various proportions, but always in relatively large numbers in the quartz of gneiss and the younger schistose rocks."

Gilligan (1919), in a study of the Millstone grit of Yorkshire, classified the quartz grains according to the Mackie scheme, stating that the order of abundance is regular, irregular, acicular, and negative (inclusionless), but adduced no

additional evidence to support the genetic interpretation of the classification. Tyler (1936), studying the St. Peter sandstone in Wisconsin, attempted to supply this evidence by analyzing the inclusions in the grains of three granites, two gneisses, and two schists. Although Tyler considered the data corroborative, the results appear equivocal, and suggest that Mackie's law may not be of general validity. Pye (1944) reached the same conclusion from a study of the Bethel sandstone. More recently, Keller and Littlefield (1950) examined inclusions in the quartz of 35 igneous and 16 metamorphic rocks and concluded (with slight modifications) that, "agreement between Mackie's findings and those of the writers is close."

Krynine (1940), discussing the Third Bradford sand, cites the work of Mackie and Gilligan, but makes the following statement, which runs counter to these earlier authorities:

"Igneous quartz contains inclusions: minute cavities at times filled with bubbles of water or CO_2, dust, and microlites of such igneous minerals as zircon, monazite, tourmaline. *The inclusions in metamorphic quartz are usually much more acicular in character* and include microlites of such stress minerals as kyanite and silimanite."

(The italics are mine.) Krynine also sums up the ideas underlying the use of extinction as a criterion of paragenesis:

"It is known that when quartz is subjected to considerable pressure it develops 'strain shadows' or 'undulose' extinction, observable under crossed nicols. The stronger the pressure the more pronounced the strain shadows."

Additional criteria of grain shape, outline, and makeup are also introduced:

"In the case of large, equidimensional grains the dividing line between modified igneous quartz and metamorphic quartz is set arbitrarily at the appearance of well-defined crenulated borders. These borders are characteristic of metamorphic quartz. Elongated (lensoid) or multiple small grains obviously can be assigned to the metamorphic group without difficulty."

With the aid of these criteria he differentiated seven types of quartz occurring in the Third Bradford sand. These fall into two broad provenance groups of igneous and metamorphic-sedimentary.

While Krynine's scheme of classification is more comprehensive and on a much firmer basis than any of the preceding, it contains several points of weakness: 1) In graywackes, crenulated borders, the criterion relied upon to distinguish modified igneous quartz from equidimensional grains of metamorphic quartz, may be difficult to distinguish from embaying due to marginal replace- by the chlorite-serecite matrix in which the grains repose. The same problem may exist in orthoquartzites as a result of contact phenomena such as welding and suturing of adjacent grains. 2) The dividing line between coarse metamorphic and schistose grains is artificial and subjective, being merely a matter of size. 3) Differentiation between slightly elongate grains and almost equidimensional ones is entirely subjective. 4) Many grains contain no inclusions. 5) Undulose extinction is not present in all grains of metamorphic origin, nor is it entirely restricted to such grains, fragments of igneous derivation not infrequently displaying strain shadows.

The two entirely valid criteria suggested by Krynine appear to be shape and the composite nature of some grains. The latter can immediately be placed in the metamorphic-sedimentary category. The problem, then, becomes one of determining whether single grains can be separated into two or more provenance groups solely on the basis of shape. Underlying the use of shape as a criterion of provenance is the assumption that dynamic metamorphic processes produce quartz approaching in form that of other tabular or acicular metamorphic minerals, whereas the shape of igneous quartz reflects its origin in an essentially isotropic stress environment.

It seems clear that, "except for slight shape modification produced by abrasion, the end shape of a sand grain or pebble appears to be determined by its original shape" (Pettijohn, 1949, p. 54).

PRESENT STUDY

Methods

A solution to the problem was arrived at in two steps. The first consisted of determining the ratios of elongation for a number of grains from 31 thin sections of the Stanley and Jackfork sandstones. This ratio is found by dividing the long axis of a grain—the diameter of the largest circle that can be circumscribed about it—by the short axis—the longest line that can be drawn normal to the long axis, not necessarily through the center of the grain. The measurements were made under the high power lens with the aid of a micrometer ocular. To insure random selection of grains, traverses were made by moving the slide along a straight edge and measuring every grain that was intercepted by the micrometer scale.

The actual elongation of a grain can be measured only if the grain is oriented in a manner such that the plane defined by its long and short axes is parallel to the plane of the thin section, in which the measurements are being made. Since this occurs only rarely, most of the values measured are intercepts of some two of of the true axes in the plane of the thin section, and the elongations so calculated differ from the true ratios accordingly. Since the true elongation is the largest value that can be measured, the mean of a large number of measured elongations will be somewhat less than the true mean. This effect is offset to some extent by the fact that the value of the true elongation is given by any pair of intercepts which are in that ratio. Furthermore, all samples are affected in a like manner, so that the validity of the comparions is in no way impaired.

Four assumptions are basic to all elongation measurements: 1) The grains are randomly oriented within the rock. The existence of a preferred dimensional orientation would bias the measurements in one of several directions, depending on how the particular thin section were cut with respect to the fabric. The nonexistence of such a fabric has been demonstrated in two ways. Three mutually perpendicular thin sections were made from each of several samples, and a number of grains measured in each. The mean elongations determined from each slide were found to be essentially the same. Dimensional fabric diagrams were also prepared for a number of slides by measuring the azimuths of the long axes of a number of elongate grains and plotting the results as histograms with class intervals of twenty degrees. None of the diagrams so constructed displayed a pronounced maximum although many of them showed a weak central tendency. 2) No significant percentage of the grains is elongated by secondary overgrowths. This phenomenon might be particularly important in orthoquartzites and subgraywackes, where a considerable per cent of the cement is secondary. A close check revealed the fact that few grains were markedly elongated by secondary enlargement, and when such a grain was encountered the overgrowth could be taken into account. It is not believed that many overgrowths passed undetected. 3) No significant percentage of the grains is elongated as a result of metamorphism affecting the Stanley and Jackfork formations. Even were this not true, one might expect that the grains from each would, on the average, be affected in a like manner rather than differentially. 4) Most of the grains measured are whole, and not fragments of larger, single grains.

Several checks were made to determine the minimum number of grains that had to be counted per thin section to yield reproducible results. Up to 350 grains, in groups of fifty, were counted in a single section. The mean, median, and standard deviation for each cumulative group (50, 100, 150, etc.) were then computed and compared. Only slight,

TABLE 1.—*Elongation values*

No.	1.0–1.2	1.2–1.4	1.4–1.6	1.6–1.8	1.8–2.0	2.0–2.2	2.2–2.4	2.4
Stanley graywackes								
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
126	19	26	21	12	5	8	3	6
135	26	24	15	13	6	6	—	10
120	29	27	11	11	7	4	5	6
121	29	22	12	13	8	4	6	6
131	31	27	16	12	3	5	2	3
115	30	27	13	6	4	7	3	10
13	22	28	17	13	3	4	2	12
165	30	19	18	12	11	2	3	5
144	31	22	20	4	9	2	4	8
145	24	23	18	11	7	6	4	7
172	23	21	23	16	2	5	5	5
173	33	14	18	10	7	9	1	8
174	30	20	15	11	10	8	2	4
166	25	25	22	13	4	7	2	2
164	35	24	12	11	3	3	2	10
Average	27	23	17	11	6	6	3	7
Jackfork subgraywackes								
21	18	19	14	13	9	10	5	12
219	23	20	17	8	11	6	4	11
139	19	21	11	11	10	9	6	13
138	12	19	18	15	12	10	2	12
242	7	13	26	17	13	11	4	9
238	15	14	20	13	10	9	5	14
233	24	16	17	12	8	10	3	9
248	13	16	21	13	12	9	7	9
245	20	16	15	16	9	10	7	7
225	16	11	20	12	15	9	9	10
231	16	18	18	10	11	8	12	7
250	17	19	22	11	13	5	6	7
251	12	19	23	13	10	11	2	10
246	16	19	23	15	9	4	6	8
249	14	20	21	19	9	3	4	10
Average	16	17	19	13	11	8	6	10

non-systematic variations existed, indicating that 100 grains is adequate to reveal the elongation characteristics of a single sample.

The arithmetic mean, median, and standard deviation were computed for the elongation data of each thin section. To facilitate these calculations, as well as for purposes of graphical representation, the data were grouped into classes, the intervals of which are 0.2. That is, all grains with elongation ratios between 1.0 and 1.19 fall into the first class, those between 1.2 and 1.39 into the second, etc.

The second step in the solution consisted of measuring the elongations of several hundred loose quartz grains from a granite, a gneiss, and a mica schist. The samples were obtained from deeply weathered till stones which could be reduced to their constituent grains without breakage, and the grains selected for measurement by picking them out of a population of quartz, feldspar, mica, and amphibole grains under a binocular

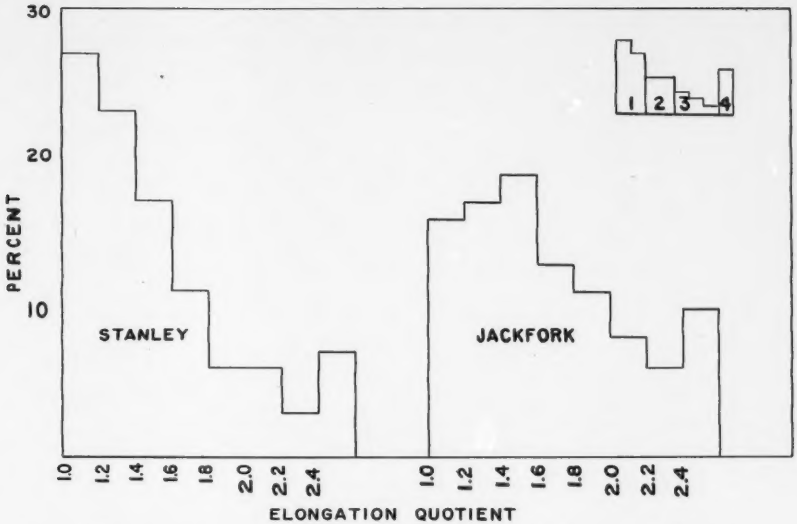

FIG. 1.—Elongation distributions of approximately 3000 quartz grains from Stanley and Jackfork sandstones. Small histogram indicates grouping of classes for analysis.

microscope. No attempt was made to separate the feldspar from the quartz, as such would have been very tedious and it was anticipated that the shapes of both would vary in similar fashion in the two rock types. The results of the measurements substantiated the validity of this expectation. The ratios obtained should be fairly close to the actual values, as the stable position of repose which each grain tends to assume when scattered on a slide is one in which the long axis and one of the other two axes lie in the plane of the microscope stage.

RESULTS

The results of each step are discussed separately and then considered together. First to be examined are those involving the thin sections from the Stanley and Jackfork sandstones. In table 1 are tabulated for 30 thin sections the percentages of grains that fall into each elongation-ratio class. The average value is given at the foot of each column, and these averages graphically represented in the two histograms of figure 1. Each slide is based on at least one hundred grains, so that each histogram portrays the elongation distribution of about 1500 grains. Table 3 gives the average values for the mean, median, mode, and standard deviation.

Examination of the tables and histograms reveals the following facts:

1. The mean elongation of all Stanely thin sections is less than that of any Jackfork section; the average values differ by 0.16 (1.71–1.55).

2. The medians likewise differ, the amount for the over-all averages being 0.18 (1.58–1.40).

3. The modal class of the Stanley histogram is the 1.0–1.2 class, and of the Jackfork the 1.4–1.6 class.

4. The standard deviations of the two are not significantly different.

The differences amount to 13 per cent in the case of the median, 10 per cent for the mean, and 35 per cent for the mode. Although relatively small, their persistence and uniformity throughout all

the samples measured indicates that they are significant.

To facilitate analysis of these differences, the classes have been placed in four groups. Reference to the histograms (fig. 1) is helpful here. Group I consists of the 1.0–1.2 and the 1.2–1.4 classes; Group II the 1.4–1.6 and the 1.6–1.8 classes; Group III the 1.8–2.0, the 2.0–2.2, and the 2.2–2.4 classes; and Group IV the greater than 2.4 class. Table 2 lists the percentages in each group for both the Stanley and Jackfork and the per cent by which the larger exceeds the smaller within each group. The greatest differences between the Stanley and Jackfork appear in Groups I and III and the smallest difference in Group II. This suggests that a population of grains from either a Stanley or a Jackfork sandstone consists of a mixture of two end members,

TABLE 2

Sandstone	Group			
	I	II	III	IV
Stanley	50	28	15	7
Jackfork	33	32	25	10
Difference (Per cent)	56	11	68	43

represented by Groups I and III (and IV), which range over a considerable latitude of values, their contiguous extremes overlapping. This zone of overlap is represented by Group II. Fluctuations in the amount of either end member present are considerably greater than variations in the mixed zone, as it shares the attributes of both end members. Group IV contains only a small percentage of the populations and is not instrumental in determining the characteristics of the distributions. It may possibly be related to the tendency of quartz to fracture into splintery grains (Alling, 1950, p. 140).

It now remains to be seen what significance can be attached to the end members defined on the basis of the elongation distributions. The results of the second step in the investigation are germane to this matter. The histograms of figure 2 summarize the quartz (and feldspar) grain elongation characteristics of a granite and a mica schist. The histograms are quite dissimilar and at the same time bear a striking resemblance to those of the Stanley and Jackfork sandstones, respectively. Table 3 summarizes the comparable parameters. The median for the schist is 23 per cent greater than

TABLE 3

Parameter	Stanley	Granite	Jackfork	Schist
Mean	1.55	1.43	1.71	1.75
Median	1.40	1.38	1.58	1.70
Mode	1.10	1.30	1.50	1.50
Standard Deviation	2.10	1.60	2.20	2.30

that for the granite, the median of the Jackfork 13 per cent greater than that of the Stanley. Examination of a number of additional grains revealed the fact that many fragments from the schist are considerably flattened, a fact that would not be apparent from the elongation measurements.

The obvious conclusion to be drawn from the data is that the detritus (Stanley graywackes) characterized by the smaller mean grain elongation is primarily of igneous derivation, whereas that characterized by the larger average grain elongation (Jackfork sandstones) came primarily from metamorphic sources. No method presents itself for determining the actual percentages of igneous and metamorphic grains in any given sample, each one being a mixture of two end members, as previously pointed out. The statistical approach has two advantages, however. First, the subjective element is practically eliminated, and second, individual grains do not have to be arbitrarily assigned to one or the other of the two provenance classes, a thing which may often be impossible to do, since a grain falling in the area of overlap could belong to either class. Rather, whole

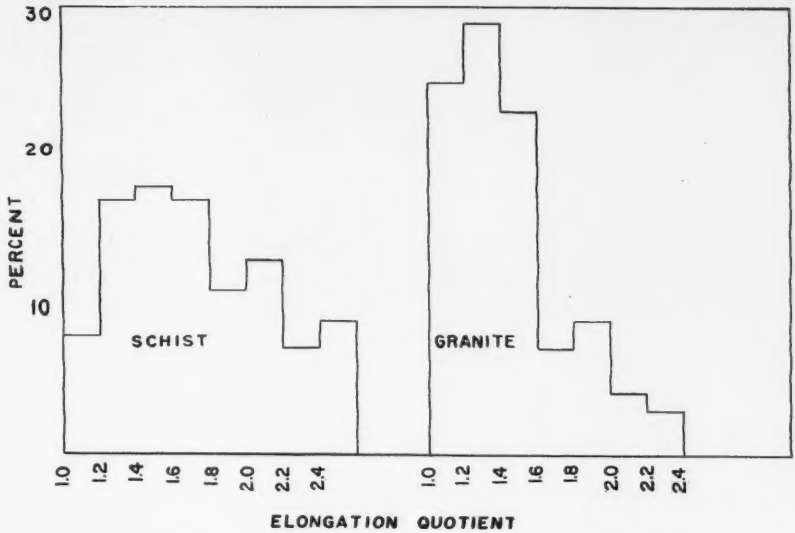

FIG. 2.—Grain elongation distributions of a granite and a mica schist.

populations of grains can be treated statistically and described by certain significant parameters and these parameters compared.

CONCLUSION

It has been shown that quartz can be used as a tool in reconstructing the sources of clastic sediments in a manner that takes into account only those characteristics which are actually definitive and evaluates them in a manner that minimizes the subjective tendencies of the observer. Further refinement of the classification so obtained many be possible but awaits further investigation. The use of quartz in provenance analysis should afford a valuable supplement to heavy mineral studies, which up until the present have been the primary concern of the sedimentary petrologist. In many cases the use of quartz may be particularly valuable, as the apparent ease with which many heavy minerals are affected by intrastratal solution makes all but the most recent assemblages suspect. Those of many older Paleozoic sediments may represent only the most stable remnants of a once much more diversified suite, and thus be practically useless for provenance studies. Such is not the case with quartz, which should be a usable tool in all sediments which have not been so altered that the original grain boundaries are no longer recognizable.

REFERENCES

ALLING, HAROLD L., *1950*. Initial shape and roundness of sedimentary rock mineral particles of sand size: *Jour. Sedimentary Petrology*, vol. 20, pp. 133–147.

GILLIGAN, A., *1919*. The petrography of the Millstone grit of Yorkshire: *Geol. Soc. London Quart. Jour.*, vol. 75, pp. 260–262.

KELLER, W. D., and LITTLEFIELD, ROMAINE, F., *1950*. Inclusions in the quartz of igneous and metamorphic rocks: *Jour. Sedimentary Petrology*, vol. 20, pp. 74–84.

KRYNINE, P. D., *1940*. Petrology and genesis of the Third Bradford sand: *Pennsylvania State Coll. Bull.* 29.

MACKIE, W., *1896*. The sands and sandstones of Eastern Moray: *Edinburg Geol. Soc. Trans.*, vol. 7, pp. 148–172.

PETTIJOHN, F. J., *1949*. *Sedimentary rocks:* Harper and Bros., New York, 526 pp.

PYE, W. D., *1944*. Petrology of the Bethel sandstone of south central Illinois: *Am. Assoc. Petroleum Geologists Bull.*, vol. 28, pp. 717–741.

TYLER, S. A., *1936*. Heavy minerals of the St. Peter sandstone in Wisconsin: *Jour. Sedimentary Petrology*, vol. 6, pp. 72–77.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 25–28
FIGS. 1–5, MARCH, 1952

RELATION OF SURFACE ANGLE DISTRIBUTION TO PARTICLE SIZE DISTRIBUTION ON ALLUVIAL FANS

ERICH BLISSENBACH[1]
Universität München, Germany

ABSTRACT

The rate of change in the maximum particle size along the radial profile of an alluvial fan approximately equals the rate of change in the slope of the fan surface. This relationship is found on non-dissected fans; it offers a possibility for reconstructing the surface of alluvial fans in cases where erosion and tectonic movements have obscured the original gradients.

INTRODUCTION

The purpose of the investigations described in this paper was to determine whether a relationship between the surface angle distribution and the particle size distribution on alluvial fans could be detected.[2] Field studies were carried out on alluvial fans of the Santa Catalina and Tucson Mountains, southern Arizona, and on fans of the Aubrey Cliffs, northern Arizona.

Both surface angle and particle size distribution were determined along the same radial profile of the alluvial fans. The angles of dip of fan surfaces were measured with the clinometer of a Brunton compass. The maximum particle size along certain points of the radial profile of a fan was determined in order to establish the particle size distribution. In both particle size and surface angle distribution curves, the horizontal axis denotes the distance from the apex on a particular fan. The vertical axis gives the maximum particle size in centimeters and the angle of dip of the fan surface in degrees, respectively. All scales employed are of arithmetical order.

[1] Sponsored by Edwin D. McKee, University of Arizona, Tucson, Arizona.

[2] This paper is part of a study on the geology of alluvial fans in Arizona submitted to the Department of Geology of the University of Arizona, Tucson, as a Master's thesis. The aid and counsel of Prof. Edwin D. McKee, under whose guidance this work was carried out, is sincerely appreciated.

FINDINGS

During the present investigation both a particle size and a surface angle distribution curve were established for an alluvial fan of the Santa Catalina Mountains, Arizona. Where the scales of these curves were chosen so that both the maximum particle size and the surface angle at the apex of the fan were expressed by the same length on the vertical axis, both curves were found similar (figs. 1 and 2).

To determine whether a similar relationship between surface slope and particle size distribution was applicable to other alluvial fans, studies were carried out on an alluvial fan of the Tucson Mountains, Arizona (fig. 3), and on two fans of the Aubrey Cliffs, Arizona (figs. 4 and 5). From the resulting diagrams (figs. 1 and 2; 3, 4 and 5) it appears that the rate of change in maximum particle size on these fans equals the rate of change in surface slope.

The distribution curves shown in the figures are obtained from non-dissected fans, or from fans so dissected that they exhibit conspicuous fan-mesas from which the original surface dip can be read. No satisfactory results in establishing a relationship between particle sizes and surface slope were obtained on alluvial fans on which the original deposition surface had been largely destroyed by erosion.

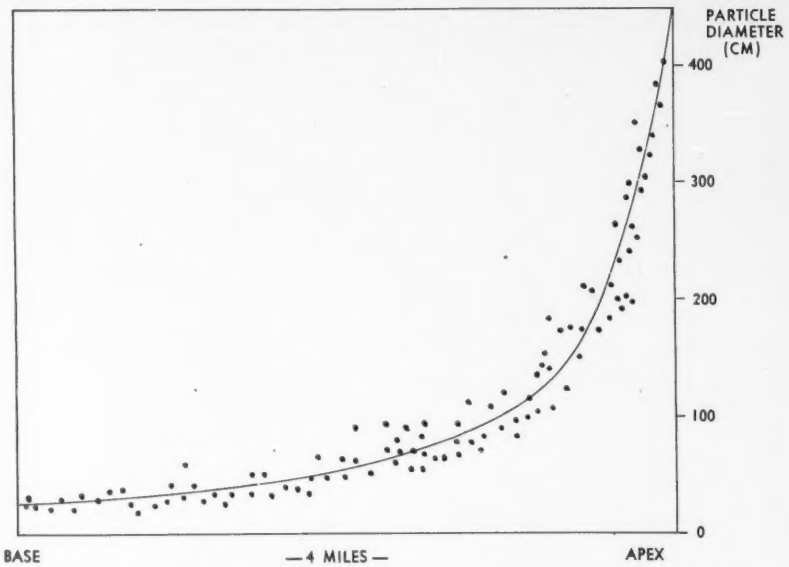

FIG. 1.—Distribution of maximum particle sizes along a radial profile on an alluvial fan of the Santa Catalina Mountains, Arizona.

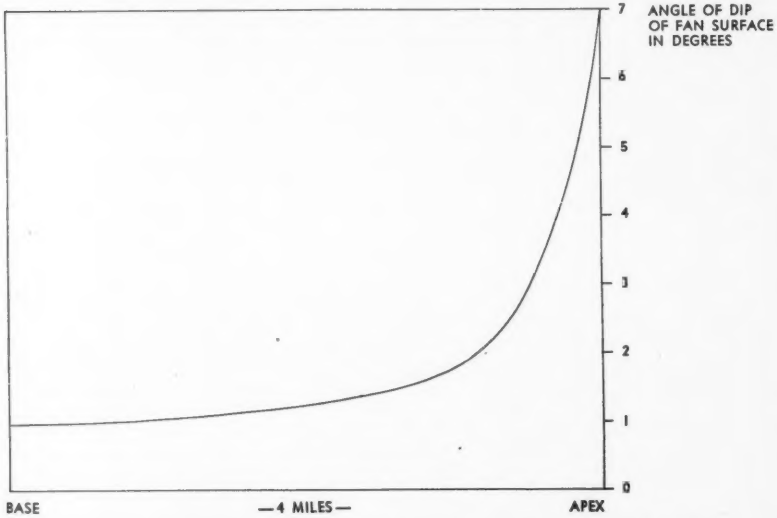

FIG. 2.—Distribution of angles of dip of the surface of an alluvial fan of the Santa Catalina Mountains, Arizona; along the same radial profile as in fig. 1.

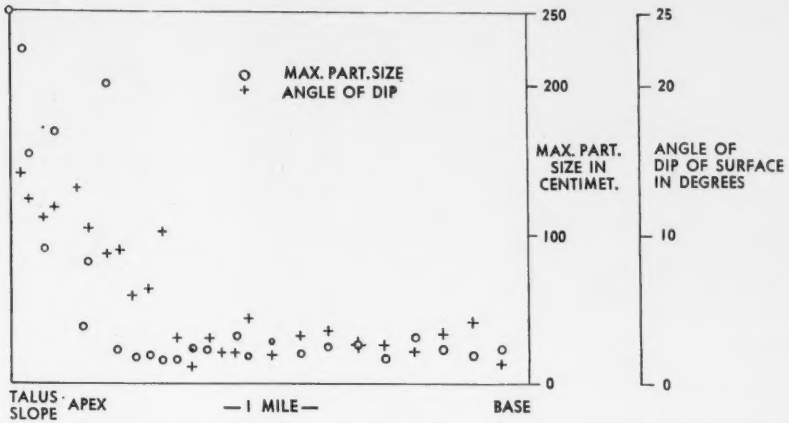

FIG. 3.—Relation between maximum particle sizes and angles of surface slope on a talus slope and adjacent alluvial fan of the Tucson Mountains, Arizona.

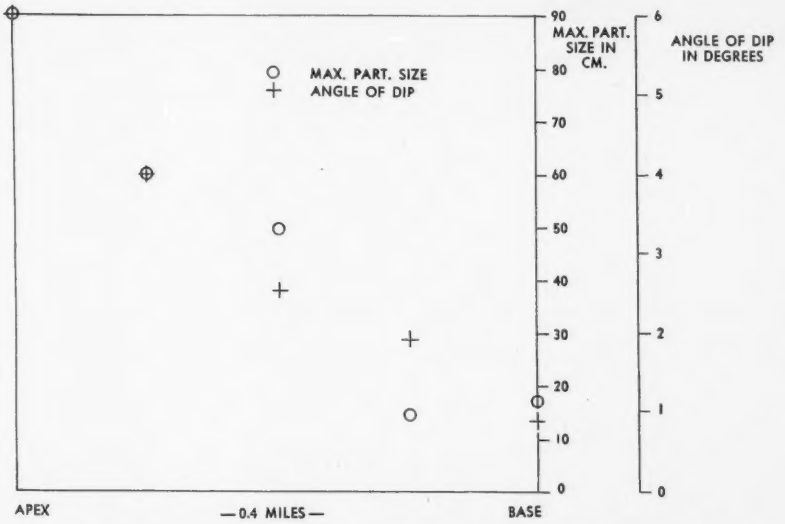

FIG. 4.—Relation between maximum particle sizes and angles of surface slope on an alluvial fan of the Aubrey Cliffs, Arizona.

DISCUSSION OF FINDINGS

Both size of gravels and gradient of a single stream are related, under the same general law, according to Barrell (1925). As distribution curves of particle sizes and surface slopes of coarse-clastic deposits follow exponential functions, as demonstrated by Krumbein (1937), a close relationship between particle size and surface slope distribution seems

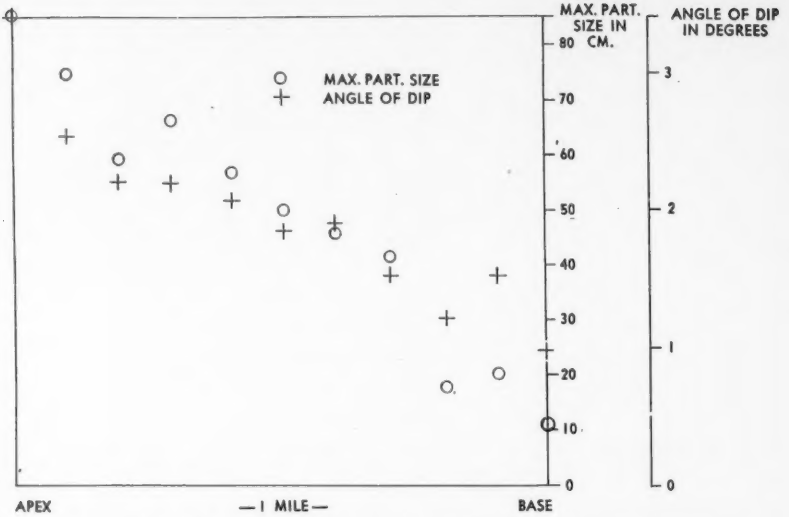

FIG. 5.—Relation between maximum particle size and angles of surface slope on an alluvial fan of the Aubrey Cliffs, Arizona.

obvious. The writer believes that he has obtained field evidence for such a relationship on alluvial fans.

In a study of this phenomenon on an alluvial fan of the Tucson Mountains, Arizona, a talus slope between the mountain front and the apex of the fan was included in the investigation. From the diagram obtained (fig. 3) it appears that the relationship found for alluvial fans may also be applicable to talus slopes. Such a relation between the rates of change in particle size and surface slope may constitute one of the fundamental principles controlling the sedimentation of most coarse detritus.

The practical importance of this close relationship rests in the possibility of assigning a certain surface slope distribution to a given particle size distribution, and vice versa. Such procedure might help to reconstruct surfaces of deposition in cases where erosion or tectonic movements have obscured the original gradients.

For further studies it is suggested that the mean particle size be employed to establish particle size distribution on alluvial fans and that accurate surveying instruments be used to determine the slope of fan surfaces. In order to investigate whether a relationship between surface slope and particle size distribution is applicable to clastic deposits other than those of alluvial fans, studies should be carried out on river and beach sediments.

REFERENCES

BARRELL, J., *1925*. Marine and terrestrial conglomerates: *Geol. Soc. America Bull.*, vol. 36, pp. 279–342.

KRUMBEIN, W. C., *1937*. Sediments and exponential curves: *Jour. Geology*, vol. XLV, pp. 577–601.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 29–32
FIGS. 1, 2, MARCH, 1952

POSSIBLE UTILIZATION OF ELECTROPHORETIC PHENOMENON FOR SEPARATION OF FINE SEDIMENTS INTO GRADES

GEORGE TCHILLINGARIAN
University of Southern California

ABSTRACT

Cataphoretic velocities appear to be a suitable means for estimating the grain size of fine sediments.

ACKNOWLEDGMENT

The investigator is indebted to Dr. K. O. Emery and Dr. D. H. Larsen for suggesting the problem and contributing some helpful advice.

INTRODUCTION

Complex phosphates and tanstuffs, which are the most effective dispersing agents, are capable of yielding spatially extensive anions which plate the clay particles of sediment suspensions. The complete plating of all the clay particles yields maximum deflocculation, probably because particles on gaining more negative charges repulse each other with greater strength. Therefore it was believed that on adsorption of negative charges, the clay particles of various sizes will exhibit different response to an electric field.

The formula for electrophoresis as shown in various textbooks is: $u = \zeta XK/4\pi n$ (Thomas, 1934, p. 228) where u is volocity of suspended particles; K, dielectric constant of medium; X, the potential gradient resulting from the applied e.m.f.; ζ, difference in potential between the layers of charges affixed to the particles and the layer of balancing charges in the liquid bathing the particle; n, viscosity of the medium through which the particle is moving. This formula shows that the velocity of a particle is independent of its shape or size.

APPARATUS

The apparatus used for this work utilizes the ultra microscope principle of illumination, with the electrophoretic cell immersed in a water thermostat. A galvanometer lamp provides an adequate source of illumination, the water in the thermostat serving as a filter for the heat rays. The electrophoretic cell is made from Pyrex glass, with capillary tubes of uniform bore and ground-in hollow stoppers to which the electrodes are attached (fig. 1).

The use of platinum electrodes enables the whole cell to be cleaned with chromic acid and a coating of platinum black on the surface minimizes the gas evolution. The volume of the suspension to fill the cell is about 3 to 4 ml.

EXPERIMENTAL METHODS

The kaolinite clay which had been leached and dialized was used in the present work. Monodisperse fractions in microns (1 to 2, 2 to 4, and 4 to 6) were obtained by means of ultra-centrifuge with settling times computed by Stokes' law. Sodium hydroxide, the dispersing agent, was measured in terms of millimoles per gram of dry clay. The suspension was aged for three days before any mobility determinations were made. An e.m.f. of 100 volts, supplied by batteries, was impressed across the electrodes and the passage of individual particles across one division on the ocular scale was timed with a stopwatch.

EXPERIMENTAL RESULTS

Table 1 shows the variation of velocity in microns with different concentrations of NaOH.

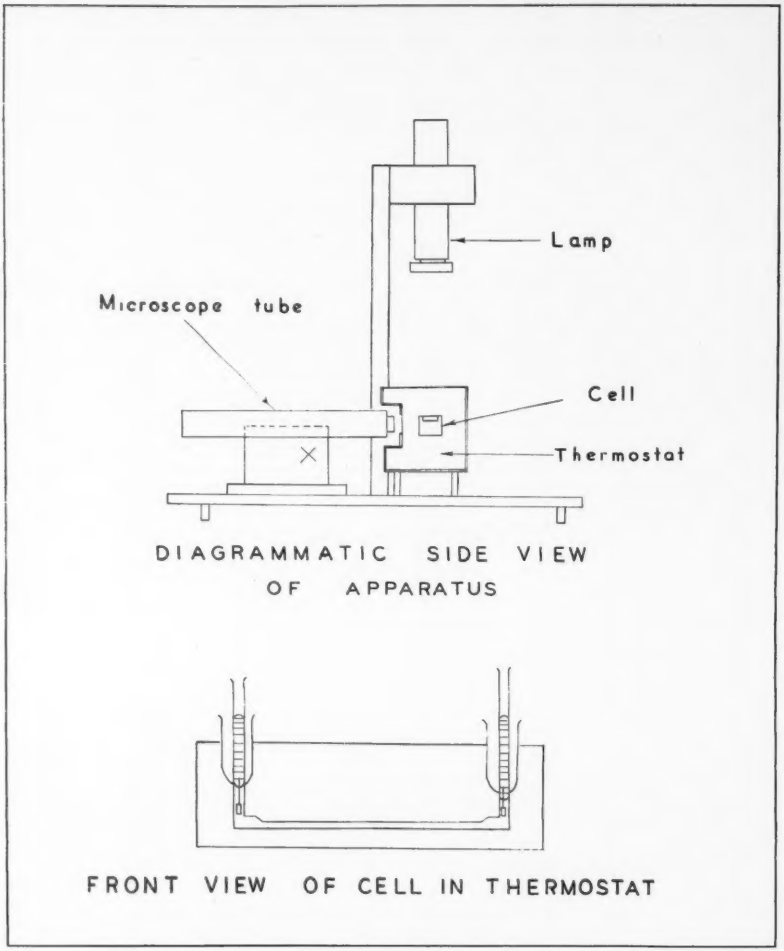

FIG. 1.—Apparatus for cataphoretic velocity determinations.

In figure 2, the particle size in microns is plotted against cataphoretic velocity. An inverse relationship between size and velocity of clay particles treated with NaOH is shown. Results shown in table 1 also demonstrate that the velocity of clay particles without NaOH is independent of particle size. The greater velocity of small clay particles can be explained by the fact that when clay particles are broken into smaller sizes, they give rise to more edges and corners which constitute the adsorption areas of kaolinite particles.

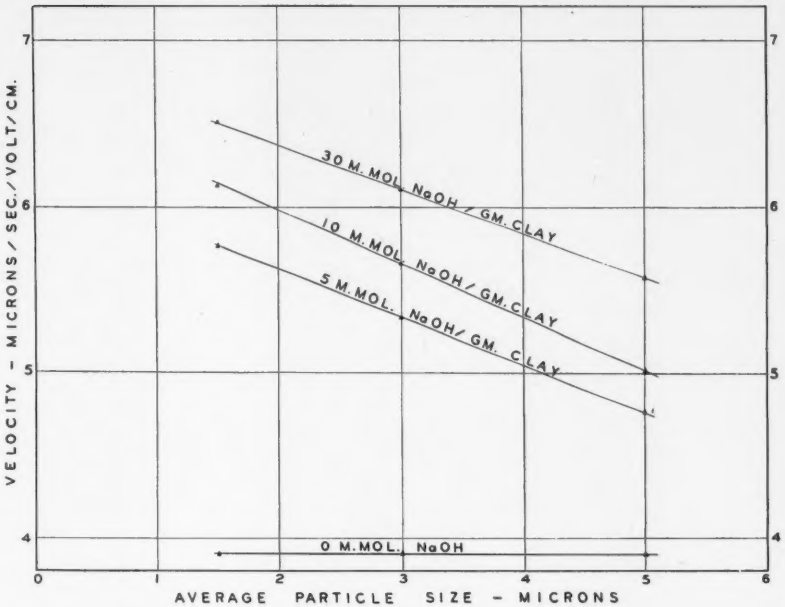

FIG. 2.—Velocity of clay particles towards positive electrode versus particle size.

TABLE 1.—*Velocity of kaolinite particles with varying concentration of NaOH*

NaOH—M.Mol./Gm. Clay	Velocity—/Sec./Volt/Cm.		
	1–2μ	2–4μ	4–6μ
0	3.9	3.9	3.9
5	5.75	5.35	4.75
10	6.13	5.63	5.00
30	6.5	6.12	5.55

The dispersing action of NaOH is apparently due to adsorption of the OH^- ions on the clay particles. Table 1 shows that the velocities of the clay particles increase with increased concentration of NaOH. However, this effect is less with greater concentration of NaOH, probably because unsaturated bonds of kaolinite particles are eventually satisfied on addition of OH^- ions. When the addition of this electrolyte is carried beyond the range indicated, a flocculation of the system occurs because the excess influx of Na^+ ions results in neutralization of OH^- ions adsorbed on clay particles. This behavior has also frequently been observed by the investigator in drilling muds.

CONCLUSIONS

It was found that an inverse relationship exists between the size of kaolinite clay particles soaked in NaOH and cataphoretic velocity. This relationship can possibly be utilized in separating kaolinite clay particles into various size grades. However, before an apparatus can be designed for this purpose, further investigation must be done in order to find out whether such relationship holds true for montmorillonite and illite clays.

In addition it is also believed that concentration will have some effect upon cataphoretic velocity, which should also be evaluated.

REFERENCES

THOMAS, A. W., *1934*. [*Colloid Chemistry*] McGraw-Hill Book Company, Inc., New York and London, p. 228.

Symposium on Microbiology in Relation to the Geologic Accumulation of Organic Complexes

This symposium was presented before a joint meeting of the Paleobotanical and Microbiological Sections of the Botanical Society of America, December 28, 1949. It is published here because of its obvious interest to sedimentary petrologists.

The complete symposium consisted of the following papers:

Degradation of plant tissues in organic sediments. E. S. Barghoorn.

Part played by bacteria in petroleum formation. Claude E. ZoBell.

The function of micro-organisms in the organic matrix regarded as the mother substance of petroleum. A. C. Thaysen.

How important was decay in the origin of Paleozoic coals? James M. Schopf.

Mechanism of cellulose degradation by chemical and biological agents. Ralph G. H. Siu.

Depositional environment of source materials forming organic sediments. Irving A. Breger.

An additional paper, given on the program immediately preceding the symposium, was the following:

A comparison of tissue preservation in coalified and silicified logs. Aureal T. Cross.

The first two papers are presented in the following pages of this number of the *Journal*. The paper by Breger has been published elsewhere. The remaining papers of the symposium may be expected to appear in subsequent issues of the *Journal*.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 34–41
PLATES 1, 2, MARCH, 1952

DEGRADATION OF PLANT TISSUES IN ORGANIC SEDIMENTS[1]

ELSO S. BARGHOORN
Biological Laboratories and Botanical Museum, Harvard University, Cambridge, Massachusetts

ABSTRACT

The carbon cycle is described as a series of biological and geological processes comprising two phases: a degradative and an accumulative phase. A distinction is drawn between environments in which aerobic microbiological changes proceed at a rapid rate, as in soil, and anaerobic environments in which processes of decomposition are at a minimum, as in shallow basins such as swamps and bogs. It is suggested that there exists a spectrum of organic decay in which the aerobic processes are at one extreme while anaerobic conditions resulting in organic accumulation are at the other extreme. The degree of change and the duration of the change vary profoundly throughout this spectrum.

Various degrees of decomposition are illustrated with examples of woody materials whose environments of deposition are known and, for the more recent material, whose ages were determined by the carbon isotope method. Photomicrographs and detailed descriptive data are presented.

Degradation and ultimate decomposition of organic substances in nature is one phase of a larger process which has been aptly designated the carbon cycle. The carbon cycle in its broader aspects is a series of biological and geological processes featured by two antithetic phases. One of these is a degradative phase; the other, an accumulative phase. The two phases are inordinately unbalanced in nature with the result that the vast majority of organic carbon is rapidly returned to an inorganic form or chemically entombed in inorganic sediments. Because of this imbalance the carbon cycle, in biological terms, is most generally thought of only in reference to its degradative aspects. It is obvious, however, even by casual consideration, that in "geologically permanent" and large-scale accumulations of organic complexes, such as the fossil fuels (coal, petroleum and natural gas), we are concerned essentially with major deviations from rather than participation in the carbon cycle as ordinarily visualized.

[1] Paper presented at a joint meeting of the Paleobotanical and Microbiological sections of the Botanical Society of America, December 28, 1949, as a part of the symposium on "Microbiology in Relation to the Geologic Accumulation of Organic Complexes."

The present world-wide, growing economic dependence upon fossil energy and the foreseeable limitation of these resources (Hubbert, 1949) should logically direct interest toward the causative and accumulative aspects of the cycle of carbon and the examination and analysis of processes whereby organic residues persist in nature. In a certain sense the study of the accumulation of plant residues and their subsequent alteration constitute an area of botanical investigation which lies between microbiology on the one hand and the geological and chemical aspects of sedimentation on the other. In the following discussion interest is centered on the rôle of woody plant tissues and the changes they undergo in the formation of organic sediments.

The ultimate fate of organic complexes in nature is determined by diverse factors of the environment, physical, chemical and biological. Among the biological agents most effective in the degradative modification of plant substances are the ubiquitous organisms grouped in the fungi and bacteria (Waksman, 1930, 1938). Microbiological activity, and resulting organic breakdown, is ordinarily most rapid in a warm, moist, highly aerobic environment. These conditions

are probably fulfilled to the greatest degree in the upper levels of stable soils, particularly those in humid tropical climates. If the environment is excessively wet, and particularly if the availability of oxygen becomes deficient, however, the rate of degradation is greatly reduced. Processes of decomposition are at a minimum in stagnant, poorly drained, shallow basins such as swamps and bogs. Under these physical conditions the accumulative phase exceeds the degradative phase, and there results a gradual accretion of variously modified plant residues. In discussing the many factors involved in degradation and preservation of plant tissues, it is, therefore, desirable that a meaningful distinction be drawn between environments in which aerobic microbiological changes proceed at a rapid rate, as in soil, and the anaerobic environment obtaining in basins of aquatic deposition. This distinction is basic since the character of degradative change is greatly influenced by the degree of these contrasting conditions of biological and physical environment. It might almost be said that there exists a spectrum of organic decay in which the various aerobic processes which operate in the soil are at one extreme, while at the other extreme are the conditions of anaerobic submergence resulting in organic accumulation. Throughout this biological spectrum microbial processes induce physical and chemical changes in plant tissues incorporated in sediments, but the degree of change and the duration of change vary profoundly.

Some understanding of the degradation of plant tissues is of much significance in the adequate histological interpretation of many types of plant fossils, since the variously altered remains of plant fragments actually comprise the major source of our knowledge of the paleontological record of evolution of plant life. For the most part these fragmentary sources are plant remains which fortuitously entered basins of sedimentation in which degradative changes proceeded to varying degrees, were retarded, and eventually almost inhibited. Under certain poorly known physical and chemical conditions the infiltration of mineral salts in solution and their subsequent precipitation have resulted in unusually perfect preservation of original structure, as is well known in many silicified and calcareous petrifactions (pl. 1, figs. 5 and 6; compare with pl. 2, fig. 4). The sequence of events which *precede* mineralization, however, appears to be essentially similar to that which prevails in any accumulation of plant remains, such as in the formation of peat and other carbonaceous sediments (Barghoorn, 1949b). There seems to be no evidence that special environmental conditions have been responsible in the past for what might be termed "biological fixation" of mineralized plant fragments, i.e., their unusual retention of organic structure. The unusual conditions, in the case of petrified plant tissues, seem to be those leading to mineral precipitation rather than to the degradative alteration of the constituent plant tissues. It might justifiably be stated as a generalization that: In the anaerobic degradation of plant tissues in sediments of various geologic age there are involved fundamentally similar processes, and that these degradative processes are directly related to basic physical, chemical and structural features of the plant cell wall.

In plant tissues entombed in mineral or organic sediments one of the outstanding physical and chemical changes is characterized by gradual reduction in the amount of initial cellulose. Depending on the degree of anaerobic, or reducing conditions in the environment, there results a variable degree of "humification" and subsequent "coalification." It should be noted that in the early stages of aerobic degradation "humification" is largely a function of aerobic processes. However, all degraded plant tissues, whether "humified" or only slightly *visibly* altered in color or form are characterized by a significant reduction of original cellulose. The extent of

loss of cellulose is, therefore, basically an index of the degree of chemical and physical degradation (Jurasky, 1938; Barghoorn and Spackman, 1950). In view of this fact, which is well supported by anatomical and microchemical study, it is of interest to examine in detail the structural changes which occur during the early stages of the degradation of the cell wall (pl. 1, figs. 1–4).

To orient the significance of histological and chemical change in the degradation of plant tissues it is desirable to note certain aspects of the basic structure of the plant cell wall. As lucidly demonstrated in recent years by Bailey and co-workers, the plant cell wall is composed at its inception, after cell division, of an outermost layer, the *primary wall.* The *primary wall,* a cellulosic "pellicle", which is the initial and delimiting wall layer ordinarily increases in surface area and may vary greatly in thickness during growth and enlargement of the cell (Bailey, 1938; Bailey, 1940; Bailey and Kerr, 1935). Internal to the primary wall a *secondary wall* is frequently developed. In many cells and tissues which lack secondary walls, the primary wall may be relatively thick and occasionally comprises the entire cell wall. In wood and woody plant tissues, however, thick secondary walls characterize the major topographic and structural features of many tissues and organs. The secondary wall generally is composed largely of cellulose with lignin and other substances interpolated in close physical relationship within the cellulosic framework (Freudenberg, 1932; Frey-Wyssling 1935; Bailey, 1940). The cellulosic fraction of the wood cell wall shows a distinct birefringence when observed in polarized light. With due regard to certain chemical variables these two major constituents of the plant cell wall, therefore, may be distinguished by direct visual observation in polarized light, provided, because of its abundance, the one does not obscure the other.

The secondary wall, as distinct from the primary wall, in woody tissues often shows three discrete layers, which differ in the orientation of their cellulosic aggregates and in their degree of lignification. The innermost and outermost of these wall layers comprise relatively thin lamellae, whereas the central layer is usually much thicker. The central layer most commonly shows a helical or verti-

---

DESCRIPTION OF PLATE 1

FIG. 1.—Transverse section of wood from white pine stump recovered from post-glacial sediments found in Boston, Massachusetts, associated with an archaeological site. Age by Carbon 14 determination 3851 ± 390 years. Note total degradation of the cellulose of the central and inner layers of the secondary wall in each tracheid, whereas the outer layer of the secondary wall and adjacent primary wall is visibly intact. Stained with Ruthenium Red. ×630.

FIG. 2.—Transverse section, same specimen shown in fig. 1. The cellulosic nature of the degraded residue is demonstrated by extraction of the residual lignin. That the cellulosic residue consists in large part of the first-formed layers of the secondary walls is shown by retention of the pit torus, a structure of the primary wall. At lower left is a tracheid retaining its secondary wall. Stained with Ruthenium Red. ×690.

FIG. 3.—Transverse section, same specimen shown in fig. 1. Lignin residue of "rot holz" tissue of degraded wood following extraction of cellulose with 72 per cent sulfuric acid. The more highly lignified primary walls are well shown by the degree of coherence of the wall layers adjacent to the intercellular substance. Compare with figs. 1 and 2. ×400.

FIG. 4.—Transverse section, same specimen shown in fig. 1. Lignin residue of normal wood, following extraction of cellulose with 72 per cent sulfuric acid. Note the large amount of wall substance retained, indicating the preponderance of lignin and hence the very small amount of persisting cellulose. Compare with fig. 2. ×400.

FIG. 5.—Transverse section of stem wood of *Robinia Pseudo-Acacia* L. showing characteristic tylose development in the large early wood vessels. Untreated, stained with Heidenhains iron-alum haematoxylon and safranin. ×50.

FIG. 6.—Transverse section of silicified stem wood of *Robinia sp.* from the Tertiary (Miocene?) of Montana. Note remnants of tylose walls and retention of the original structural pattern. Removal of the silica by hydrofluoric acid and examination of the section between crossed Nicols shows the absence of a birefringent cellulose residue. ×50.

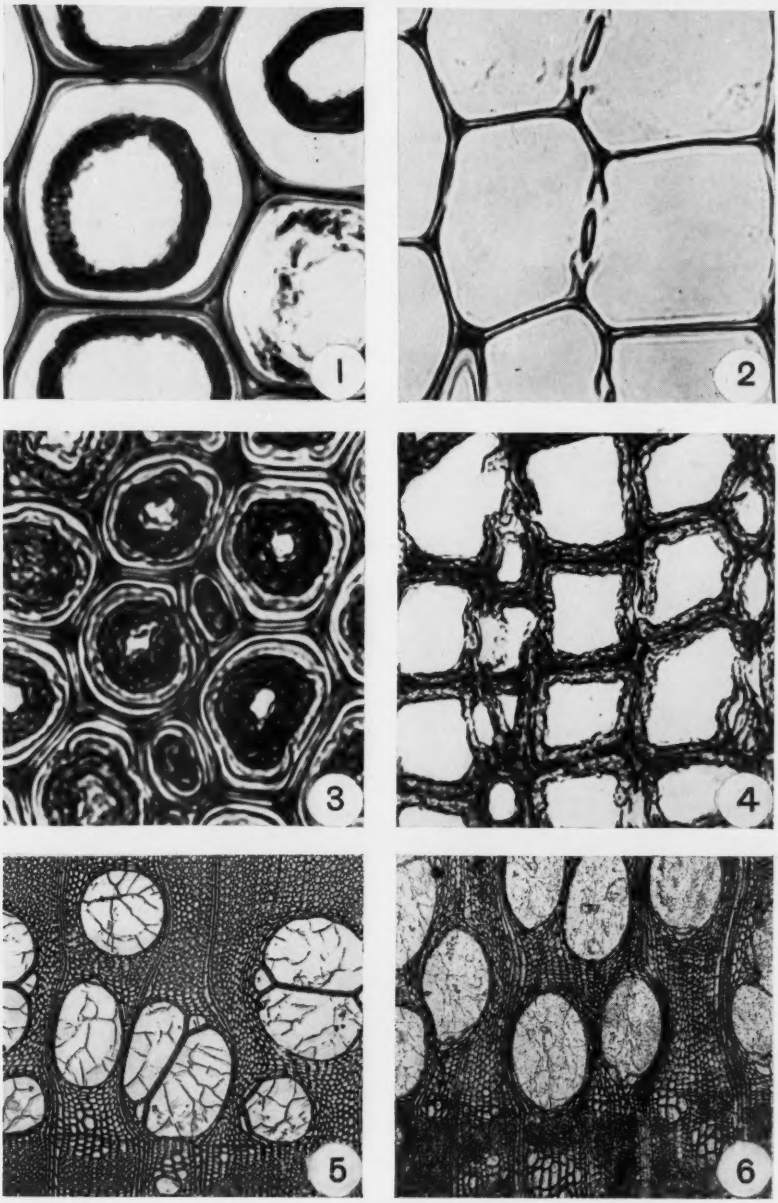

PLATE 1

cal orientation of its cellulose while the inner and outer layers show a more or less transverse orientation. All three cellulosic layers may be infiltrated to varying degrees by so-called encrusting substances such as terpenes, resins, tannin, lignin and other protective chemical complexes. In addition to lignin these subsidiary substances may exert inhibition upon biological and chemical degradation

The anaerobic degradation of wood, in accumulations of recent geologic age, provides evidence indicating a uniform and consistent sequence of degradative changes. This sequence shows a fundamental relation to the lamellar structure of the cell wall (Barghoorn, 1949a). In organic sediments, the sequence of breakdown is most frequently in the following order:

a) Central layers of the secondary wall
b) Innermost layer of the secondary wall
c) Outermost layer of the secondary wall
d) Primary wall.

A pronounced difference in the *rate* of degradation of various cellulosic layers of a *single cell wall* presents an apparent paradox in the histology and the chemistry of cellulose degradation whether this degradation be primarily biological or chemical. It should be noted in considering the problem that differential degradation of cellulosic lamellae is not an isolated phenomenon, but is apparently a consistent feature of the anaerobic decomposition of plant tissues. Two plausible explanations for this seemingly selective degradation of cellulose in contiguous layers of a cell wall are evident. One of these is the existence in the cellulosic matrix of substances which selectively retard the hydrolysis of cellulose. Another possible explanation implies essential chemical differences in the cellulosic framework of the more resistant lamellae of the cell wall. The first of the two explanations relies largely upon the well-known inhibitory effect of lignin on degradation of woody tissues, since lignin is clearly a primary factor in retarding the action of many fungi and most bacteria on wood cellulose (Olson, Peterson and Sherard, 1937; Virtanen, Koistinen and Kiuru, 1938). However,

DESCRIPTION OF PLATE 2

FIG. 1.—Tangential longitudinal section of stem wood of *Cyrilla sp.* from the Tertiary (Oligocene?) Brandon lignite of Brandon, Vermont. Note differences in the extent of structural deformation between the prosenchymatous wood elements and the cells of the rays. Extraction of the "lignin" indicates a small residue of persisting cellulose, chiefly in the less distorted cell walls of the rays. ×120.

FIG. 2.—Transverse section of stem wood of *Cyrilla sp.* from the Brandon lignite. The isolated area of structurally preserved cells is associated with wound tissue, as shown in the upper portion of the figure. Compare with fig. 3. ×135.

FIG. 3.—Transverse section of stem of *Cyrilla sp.* from the Brandon lignite showing pith and the structurally preserved wood of the first growth ring. Differential degradation of the tissues is indicated by comparing the structurally preserved areas with the peripheral, degraded and collapsed tissue. Such pronounced differences in preservation of structure indicate that the appearance of compression is effected not only by physical forces but also by chemical degradation of the wall substance. ×40.

FIG. 4.—Transverse section of root wood of white oak, found *in situ* in post-glacial sediments, Boston, Massachusetts. Age by Carbon 14 determination 5750 ± 500 years. The wood is in an advanced stage of degradation of the type which characterizes deterioration of woody plant tissues under anaerobic conditions. Microchemical examination of the wood indicates a small percentage of retained cellulose, slightly more than in the Tertiary lignite shown in figs. 1–3. ×80.

FIG. 5.—Longitudinal section of root of *Scirpus cyperinus* showing the distinctive idioblast cells which feature the epidermis of the root. ×135.

FIG. 6.—Root epidermis from post-glacial peat, Boston, Massachusetts. Age by Carbon 14 determination 5750 ± 500 years. The root is probably referable to the genus *Scirpus*. Epidermal cells, not detectably cutinized, suberized or lignified, are structurally intact, indicating the pronounced resistance to anaerobic degradation of their cellulosic cell walls. The persisting cellulose residues comprise chiefly primary cell walls. ×135.

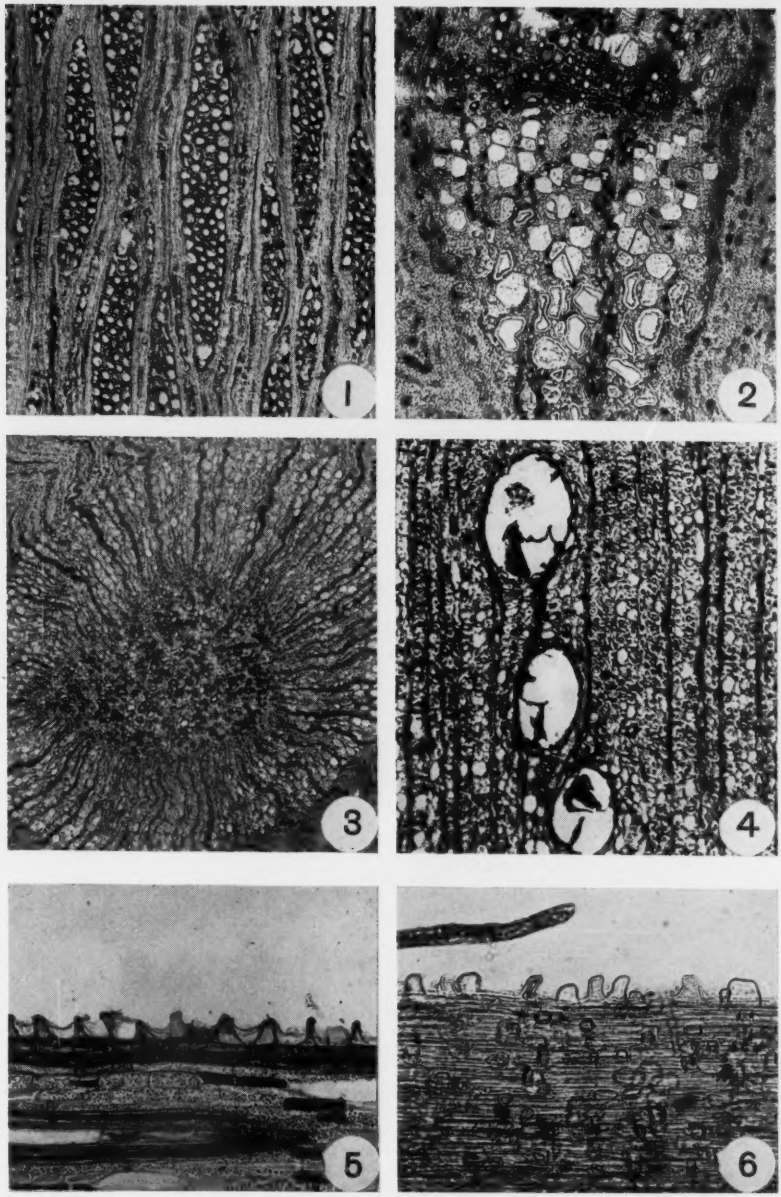

PLATE 2

examination of plant remains from fibrous post-glacial peats often shows that a large portion of the recognizable fragments in these accumulations consist primarily of delicate and *unlignified* plant residues (pl. 2, figs. 5 and 6). Conspicuous among these are the roots, rhizomes, and in some cases, root hairs of herbaceous plants (Barghoorn, 1949a).

Anatomically preserved, delicate tissues in peats are predominantly those parts of the plant, namely roots and rhizomes, which entered (by growth) into the underlying anaerobic environment in the living condition and were hence not exposed, after their death, to aerobic processes which effect decomposition on the surface of accumulation. The aerial parts of these plants, on the other hand, after their death, ordinarily are rapidly decomposed by aerobic processes on the surface, and it is these degraded fractions which comprise the bulk of the amorphous and humified portions of peats. Anatomically, therefore, *structurally* preserved residues in fibrous peats often consist primarily of unlignified primary walls, and it is a paradox that the delicate tissues of various plant organs are more resistant to anaerobic degradation, even though totally unlignified, than are cells of tissues possessing thick and frequently heavily lignified secondary walls. It seems difficult to interpret such selective degradation of cellulose in different layers of the plant cell wall except in terms of fundamental differences in the cellulosic molecular structure of successively formed lamellae of the wall.

That ultimate complete degradation of cellulose in woody tissues may be delayed even in terms of geologic time is well shown by examination of many lignites of Tertiary and Mesozoic age (Mitchell and Ritter, 1934; Jurasky, 1938; Barghoorn and Spackman, 1950). In Tertiary sediments lignitized wood may retain a large fraction of its initial cellulose even though in a highly degraded condition (pl. 2, figs. 1–3). The intensely lignified bony endocarps, or stone fruits, common in certain Tertiary lignite deposits sometimes possess as much as 50 per cent of their original carbohydrate fraction, predominantly cellulose (Barghoorn and Spackman, 1950). In geologically older deposits or in deposits which have undergone extensive tectonic disturbance there is complete elimination of detectable cellulose.

The role of cellulose, which comprises an estimated one-third of all vegetable plant substance in nature, is therefore of primary interest in detailed consideration of the source material in geologically recent organic accumulations, even though non-cellulosic components, particularly lignin and its derivatives, comprise the bulk of the plant remains recoverable from these sediments. In the aggregate, however, a large fraction of plant substance which enters sediments is cellulosic and of this an appreciable fraction remains after the presumed cessation of active microbiological processes. The remaining cellulose clearly undergoes ultimate conversion to other chemical complexes. In terms of geologic processes it is apparent, therefore, that all components of the initial plant substance participate in the accumulative phase of the carbon cycle, although in widely differing proportions and through fundamentally different bio-chemical and geo-chemical processes. A perplexing problem which still remains *empirical* is the quantitative participation of cellulose in this over-all accumulative phase in the organic cycle of carbon.

REFERENCES

BAILEY, I. W., *1938*. Cell wall structure of higher plants: *Ind. and Eng. Chemistry*, vol. 30, pp. 40–47.

———, *1940*. The walls of plant cells: *Am. Assoc. Adv. Sci. Publ. No. 14*, pp. 31–43.

——— and KERR, T., *1935*. The visible structure of the secondary wall and its significance in physical and chemical investigations of tracheary cells and fibers: *Jour. Arnold Arboretum*, vol. 16, pp. 273–300.

BARGHOORN, E. S., *1949a*. Degradation of plant remains in organic sediments: *Bot. Museum Leaflet, Harvard University*, vol. 14, pp. 1–20.

———, *1949b*. Paleobotanical studies of the Fishweir and associated deposits. The Boylston Street Fishweir II. Edited by Frederick Johnson. *Papers of the Robert S. Peabody Foundation for Archaeology*, vol. 4, pp. 49–83.

——— and SPACKMAN, WILLIAM, *1950*. Geological and botanical study of the Brandon lignite and its significance in coal petrology: *Econ. Geology*, vol. 45, pp. 344–357.

FREUDENBERG, K., *1932*. The relation of cellulose to lignin in wood: *Jour. Chem. Educ.*, vol. 9, pp. 1171–1180.

FREY-WYSSLING, A., *1935*. *Die Stoffauscheidung der höheren Pflanzen*: Berlin.

HUBBERT, M. K., *1949*. Energy from fossil fuels: *Science*, vol. 109, pp. 103–109.

JURASKY, K. A., *1938*. Wandlungen des Holzes auf dem Weg zur Kohle: *Geologischen Rundschau*, vol. 29, pp. 441–461.

MITCHELL, R. L. and RITTER, G. J., *1934*. Composition of three fossil woods mined from the Miocene auriferous gravels of California: *Jour. Am. Chem. Soc.*, vol. 56, pp. 1603–1605.

OLSON, F. R., PETERSON, W. H., and SHERARD, E. C., *1937*. Effect of lignin on fermentation of cellulosic materials: *Ind. and Eng. Chemistry*, vol. 29, pp. 1026–1029.

VIRTANEN, KOISTINEN and KIURU, *1938*. *Suomen Kemistilehti*, vol. 11, p. 30. (Abstract in *Papier Fabrik*, vol. 38, p. 22, 1940)

WAKSMAN, S. A., *193*". Chemical composition of peat and the role of microörganisms in its formation: *Am. Jour. Sci.*, 5th series, vol. 19, pp. 32–54.

———, *1938*. *Humus*: Williams and Wilkins, Baltimore.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 42–49
MARCH, 1952

PART PLAYED BY BACTERIA IN PETROLEUM FORMATION[1]

CLAUDE E. ZOBELL
Scripps Institution of Oceanography, University of California, La Jolla

ABSTRACT

Biochemically versatile bacteria, capable of catalyzing a good many chemical reactions, occur abundantly in recent marine sediments. Living bacteria detected in certain petroliferous formations at appreciable depths are believed to be indigenous species in a state of dynamic equilibrium with their environment.

If petroleum is formed from organic matter, it is almost axiomatic that bacteria have contributed to the process, because the organic remains of both plants and animals are susceptible to microbial modification. In recent marine sediments bacteria tend to convert organic compounds into humus and other substances approaching the elementary composition of crude oil.

Besides producing methane as an end-product of metabolism, certain bacteria synthesize small quantities of liquid and solid hydrocarbons as an integral part of their cell substance.

Anaerobic bacteria found in sediments catalyze the oxidation of molecular hydrogen with the formation of methane, hydrogen sulfide, saturated compounds, and other substances that may occur in oil fields.

Crude oil in contact with water may be slowly modified in various ways by bacterial activity.

Bacteria may contribute to the migration and accumulation of oil by promoting its liberation from oil-bearing sediments.

Although many theories have been advanced (Brooks, 1936; Skelton and Skelton, 1942) to account for the origin of oil, the reactions resulting in the formation of petroleum are still obscure. It is generally agreed, however, by petroleum geologists (Cox, 1946) that crude oil was formed from the organic remains of plants and/or animals in a marine environment at pressures mostly less that 5,000 psi, and at relatively low temperatures, the maximum being in the neighborhood of 100°C. for most oil basins.

Based upon the premise that organic matter is the mother substance of petroleum, it is almost axiomatic that bacteria and allied microorganisms must have contributed to the process, because virtually all known types of organic matter are susceptible to microbial modification in marine sediments. Moreover, microorganisms may have played a part in conditioning the marine environment by virtue of their effect on the hydrogen-ion concentration, redox potential (ZoBell, 1946a), state of sulfur, gas tension carbonate content, and other properties of sediments (ZoBell, 1942, 1943).

BACTERIA IN PETROLIFEROUS SEDIMENTS

Recent marine sediments rich in organic matter contain large numbers of living bacteria (ZoBell, 1938). Although their abundance decreases with depth (ZoBell and Anderson, 1936), significant numbers have been detected at the bottom of the longest marine mud cores that have been examined for the presence of bacteria. Rittenberg (1940) demonstrated the presence of numerous bacteria throughout the length of several cores, some of which were 350 cm long. Living bacteria have been detected in carefully collected cores taken near shore with a pile driver from depths exceeding 150 feet.

[1] Contribution from the Scripps Institution of Oceanography, New Series 569. This paper is a contribution from American Petroleum Institute Research Project 43A.

Paper presented at a joint meeting of the Paleobotanical and Microbiological sections of the Botanical Society of America, December 28, 1949, as a part of the symposium on "Microbiology in Relation to the Geologic Accumulation of Organic Complexes."

Bastin (1926), Gahl and Anderson (1928), Bastin and Greer (1930), Ginter (1930), Ginsburg-Karagitscheva (1933), Müller and Schwartz (1949), and several others have reported finding bacteria in reservoir fluids from depths ranging from a few hundred to several thousand feet. While there is some question as to whether these bacteria are contaminants or species indigenous to the formation where found, evidence is being accumulated, strongly suggesting that bacteria live in certain petroliferous formations. For example, Müller (1944) found bacteria in 13 out of 38 aseptically collected side-hole samples from oil sands and oil-bearing limestones. Similarly we have found bacteria in part of the cores collected from oil or sulfur wells, with all possible precautions being taken to exclude contamination.

Finding no bacteria in certain samples proves that reservoir fluids and oil-well cores can be collected without contamination, there being no reason to suspect the presence of indigenous microflora in all formations. If bacteria are alive and active, most likely they will be found only in formations containing sufficient water, minerals, available carbon, and energy source. Moreover, other environmental conditions such as pressure, temperature, pH, E_h, lack of toxics, etc., must be conducive to the multiplication and metabolism of microorganisms. Even when present it is often extremely difficult to detect bacteria in certain sediments, since they may require long periods of incubation and special conditions for growth. It is amazing that some bacteria seem to withstand the shock of being transplanted abruptly from environments where extremes of temperature, hydrostatic pressure, salinity, redox potential, etc., prevail, to laboratory conditions.

Finding in petroliferous sediments almost exclusively anaerobic sulfate-reducing bacteria, and rarely any aerobes that predominate in surface soil and water, is highly significant, though not conclusive evidence, for their indigenous origin. Some of these have been shown to be able to grow in oil-well brines enriched with crude oil (ZoBell, 1950) or molecular hydrogen (ZoBell, 1947) as the sole source of energy. Also suggestive of the indigenous nature of certain bacteria isolated from oil wells is the observation that they grow best or exclusively at temperatures, pressures, and salinities characteristic of the formation. Recently we have worked with sulfate-reducing bacteria from depths of 9,000 feet which were most active at around 5,000 psi, whereas most bacteria isolated from near surface material are inhibited or killed when subjected to such hydrostatic pressures (ZoBell and Johnson, 1949).

That bacteria may be active in petroliferous sediments is indicated by the frequent decreased sulfate and increased sulfide content of brines associated with crude oil. While inorganic reactions might account for the reduction of sulfate, it has been established that bacteria could be responsible for this change (Ginter, 1934, ZoBell and Rittenberg 1948). Likewise, the common absence of hydrogen in oil fields, where one might expect it as a by-product of radioactivity (Honig and Sheppard, 1946), bacterial fermentations (ZoBell, 1947), or certain chemical reactions (Nichols, 1941), may be attributable to the action of bacteria in sediments which utilize this gas. Observed changes with depth or age, in the amount and properties of organic matter in long cores of recent sediments, are believed to be attributable to bacterial activity, because in vitro tests under simulated conditions similar changes have been produced.

While only a few specialized bacterial species have been detected in older sediments, there occur in recent sediments a large variety of microorganisms capable of attacking all kinds of organic compounds as well as capable of catalyzing numerous inorganic reactions. In recent sediments both anaerobes and aerobes exist, the latter predominating in surface materials. The number and variety of chemical reactions known to

be catalyzed by bacteria far exceed those attributable to all plants and animals together (Stephenson, 1947) Bacteria owe their biochemical versatility to the vast array of enzymes (biocatalysts) which they produce. There are varieties that thrive throughout the entire range of environmental conditions encompassed by the "geological fence" for the origin of oil (Cox, 1946), and, in the presence of food and energy, they may multiply with amazing rapidity.

MODIFICATION OF ORGANIC MATTER

Except in preservative environments, the organic remains of plants and animals start to undergo microbial modification shortly after the death of the organisms. In the presence of free oxygen much of the organic material may be oxidized or mineralized by microorganisms with carbon dioxide, ammonia, water, and sulfate being produced. In this process from 30 to 40 per cent of the organic carbon may be converted into bacterial cell substance. Part of the latter may be quite complex, and together with complex organic substances of plants and animals that are also relatively resistant to microbial decomposition, go to make up marine humus. The humus content of marine sediments will be highest in environments where organic production is large, the rate of sedimentation is fast, and where conditions are anaerobic. It is in such environments that protopetroleum is believed to be deposited.

As elaborated by Waksman (1933, 1935, 1936), humus is an accumulation of substances of plant, animal, and bacterial origin, that is fairly but not absolutely resistant to microbial decomposition. It has a higher carbon content than the plant, animal, or bacterial substances from which it originated, usually 52 to 58 per cent, and a lower nitrogen content.

When buried in sediments, under favorable conditions marine humus may be slowly modified by a combination of microbial, chemical, physical, and geological factors, with the formation of crude oil by processes that are not well understood. In the complete absence of atmospheric oxygen, anaerobic bacteria slowly attack marine humus with the formation of substances which contain relatively less oxygen, nitrogen, sulfur, and phosphorus, leaving residual material relatively richer in carbon and hydrogen and consequently more like petroleum which consists largely of carbon and hydrogen. This may be illustrated by the following proximate analyses summarized in table 1.

TABLE 1

	Marine organisms	Marine humus	Crude oils
	Per cent	Per cent	Per cent
Carbon	45–52	52–58	82–87
Hydrogen	5–9	6–10	11–14
Oxygen	25–30	12–20	0.1–5
Nitrogen	9–15	0.8–3	0.1–1.5

The pathways by which marine humus is converted into crude oil are still obscure, but there can be no doubt that bacterial processes are largely responsible for the formation of humus. Associated with the humus in recent marine sediments are traces of liquid and solid hydrocarbons which probably come in part from decomposing plants and in part from bacterial bodies. While quantitatively the amount of hydrocarbons produced by plants (Hackford, 1932; Seyer, 1933; Chibnall, *et al.*, 1934; Sanders, 1937) may be sufficient to account for all known petroleum deposits, the author is aware of no geological evidence to explain the selective migration and accumulation of petroleum hydrocarbons exclusively from this source. Possibly such preformed hydrocarbons contribute somewhat, but the main bulk of petroleum is probably produced at some depth in older sediments as attested by the lack of evidence that any petroleum has been formed since the Pliocene (Cox, 1946).[2]

[2] Since this was written, Paul Smith (1952)

The recent observations of Whitehead and Breger (1950) on the low temperature pyrolysis of organic extract from marine sediments suggest that certain humus might be quite readily converted into petroleum hydrocarbons. Contributing mechanisms may be contact catalysis, radioactivity (Lind, 1938), bacterial activity, and other processes at temperatures prevailing within the limits of the "geological fence."

Studies on the decarboxylation of organic compounds, deamination reactions, transmethylations, and hydrogen sulfide liberation, suggest various mechanisms by which anaerobic bacteria can convert marine humus into substances more akin to petroleum. Further observations on such bacterial reactions are urgently needed to elucidate the problem of the origin of oil.

BACTERIA PRODUCE HYDROCARBONS

The anaerobic fermentation of organic matter nearly always results in the formation of methane, a common constituent of natural gas and crude oil. Methane is also formed by the reduction of carbon dioxide with either organic compounds or molecular hydrogen serving as a source of energy (Barker, 1936; ZoBell, 1947). The bacterial production of ethane has been reported (Neave and Buswell, 1938; Rawn *et al.*, 1939), and there is somewhat less conclusive evidence for the microbial formation of propane, butane, ethylene, and other gaseous hydrocarbons in small amounts.

A good many bacterial species (Porter, 1946) produce carotene, flavorhodin, and other complex pigmented hydrocarbons having the empirical formula $C_{40}H_{51-58}$, which may be susceptible to hydrogenation. It is especially significant that some of these pigmented hydrocarbons produced by bacteria possess the benzene nucleus. Phenol, cresol, and possibly other aromatic compounds commonly found in crude oil are produced by marine bacteria from the degradation of proteins (Updegraff, 1948).

Ether-soluble unsaponifiable oily extracts produced from fatty acids by sulfate-reducing bacteria were identified by elementary analysis and physical properties as a mixture of hydrocarbons ranging from C_{10} to C_{25} (Jankowski and ZoBell 1944). An optically active mixture of liquid and solid hydrocarbons was extracted from marine bacteria by API Research Project 43B workers (Whitmore, 1945). Similar observations lead the author to believe that all anaerobic bacteria produce as part of their cell substance, traces of liquid and solid hydrocarbons. Although the amount of such hydrocarbons is small, if they are more resistant to decomposition than the rest of the bacterial cell substance, hydrocarbons may gradually accumulate as the organic material is used over and over again by bacteria.

According to Bach and Sierp (1924), the anaerobic degradation of fats under natural conditions resulted in the formation of liquid hydrocarbons. An increase in the hydrocarbon content of diatoms undergoing degradation by anaerobic bacteria was observed by Clarke and Mazur (1941), one of the principal hydrocarbons produced being hentriacontane, $C_{31}H_{64}$.

HYDROGEN UTILIZATION

Bacteria which utilize molecular hydrogen may contribute to oleogenesis and also help to account for the paucity of this gas in oil fields. Free hydrogen is commonly formed during the fermentation of organic matter (ZoBell, 1947) and it may be produced by radioactivity (Lind, 1938), or by a variety of chemical reactions.

In reviewing the literature on this subject, ZoBell (1947) has pointed out

---

has reported extracting from recent marine sediments appreciable quantities of paraffinic, naphthenic, and aromatic hydrocarbons, the amount of which increased with depth throughout the length of a 103-foot core from the Gulf of Mexico. The extrapolation of his data indicated that a cubic mile of such sediment might contain 13,000,000 barrels of this extract resembling crude oil.

that several species of anaerobic bacteria found in marine sediments catalyze the oxidation of hydrogen. Some bacteria activate the hydrogenation of unsaturated compounds:

$$RHC=CHR+H_2\rightarrow RCH_2CH_2R$$

where R is an alkyl group or other organic radical. Other bacteria catalyze the reductive deamination of amino acids with molecular hydrogen:

$$RCHNH_2COOH+H_2 \rightarrow RCH_2COOH+NH_3$$

Of special interest are anaerobic bacteria which reduce carbon dioxide to methane:

$$CO_2+4H_2\rightarrow CH_4+2H_2O$$

this being an exothermic reaction yielding sufficient energy to provide for the synthesis of bacterial cells which catalyze the reaction. This may also be said of autotrophic sulfate-reducing bacteria which obtain their energy for growth from the oxidation of hydrogen:

$$H_2SO_4+4H_2\rightarrow H_2S+4H_2O$$

Finding such bacteria in oil fields may help to account for the decrease in the sulfate content and increase in the sulfide content of brines characteristic of oil fields. Such bacteria may also contribute to oleogenesis because they have been shown to produce appreciable amounts of ether-soluble unsaponifiable material. We have found enough of these organisms in petroliferous sediments to account for the formation of 6.2×10^{-10} mgm of oily material per cc of sediment per year. Although the oily material is believed to consist largely of hydrocarbons, conclusive proof is still lacking. The carbon necessary for this synthesis comes from carbon dioxide or carbonates:

$$CO_2+3H_2\rightarrow(-CH_2-)+2H_2O$$

where $(-CH_2-)$ represents a building block of bacterial cell substance, part of which may be hydrocarbon (Sisler and ZoBell, 1951).

BACTERIAL MODIFICATION OF CRUDE OIL

Virtually all kinds and classes of petroleum hydrocarbons have been shown to be susceptible to bacterial oxidation under favorable conditions (ZoBell, 1946b; 1950a). Several dozen samples of crude oil from representative fields have also been found to be attacked by bacteria. Unfortunately, very little is known regarding the changes caused by bacteria, but it is axiomatic that those crude oils which support the growth of bacteria may be modified.

Certain constituents of crude oil may be selectively decomposed or converted into other substances. Tausson and Aleshina (1932) believe that certain sulfate-reducing bacteria tend to convert paraffinic hydrocarbons higher than C_{10} into naphthenic hydrocarbons. The preferential attack of sulfur compounds and other changes in the properties of a variety of Russian crudes caused by sulfate-reducing bacteria has been reported by Maliyantz (1935). We have observed both increases and decreases in the gravity of crude oils under the influence of bacteria, the direction and magnitude of the reaction appearing to depend upon the type of bacteria present and environmental conditions.

Tausz (1919) found an increase in the asphaltic residue of Mendoza crude oil from an initial content of 0.3 per cent to 5.2 per cent as a result of bacterial activity. Bacterial activity was found by Tausson and Shapiro (1934) to affect the index of refraction, iodine number, saponification number, density, and physical appearance of Emba crude oil samples. The middle fractions and unsaturated compounds were selectively attacked in laboratory experiments.

There are several mechanisms by which bacteria attacking oil at the oil-water interface bring about the formation of water emulsions of oil. Possibly such bacterially produced water emulsions may help to account for the migration of oil. Water emulsions are caused partly by fatty and naphthenic acids

produced by bacteria from petroleum hydrocarbons, which suggests that such acids not infrequently found in oil fields may be the result of bacterial activity.

Given sufficient time and favorable conditions, bacteria can be expected to bring about the quantitative destruction of petroleum hydrocarbons in an aerobic environment. This may help to account for the absence of oil from many environments and its disappearance from sediment samples stored in the presence of free oxygen. In anaerobic environments characteristic of petroliferous sediments, crude oil constituents may be slowly and selectively attacked at the oil-water interface. Certain heavy metals, low redox potentials (ZoBell, 1946a), high concentrations of hydrogen sulfide, and other unfavorable conditions may retard or prevent bacterial activity. In a closed system the toxic metabolic products of bacteria themselves may limit bacterial activity.

In a closed system such as a petroleum deposit, anaerobic bacteria might conceivably attack hydrocarbons at the oil-water interface. However, the extent of their activity would be limited by toxic metabolic products and competition for essential nutrients. Consequently, the few surviving bacteria would soon reach a condition of dynamic equilibrium in which multiplication or reproduction would be limited by the rate of diffusion of toxic products away from, and essential nutrients into, the biosphere. This condition of dynamic equilibrium, in which bacterial activity is envisioned as being extremely slow, may be altered by diastrophism, drainage from an oil well, or by any disturbance that may promote the movement of oilfield fluids.

LIBERATION AND MIGRATION OF OIL

Bacteria growing in marine sediments may contribute to the liberation of oil from oil-bearing materials and promote its flow in various ways. Most obvious is the bacterial decomposition of the organic matrix of plant bodies bearing oil, thereby freeing oil droplets to coalesce with other oil droplets.

A second mechanism by which bacteria dissolve carbonate or sulfate rocks on which oil is adsorbed has been described by ZoBell (1947). The dissolution of such sedimentary materials may not only release adherent oil, but it may also favor the flow and accumulation of oil by the formation of void spaces and channels.

Third, bacterially produced carbon dioxide tends to decrease the viscosity of oil, particularly when under pressure. This may favor the flow of oil. Bacterially produced methane may dissolve oil or decrease its viscosity to a point where it flows more readily. When methane, hydrogen, and other gases are produced by bacteria in microtraps (ZoBell, 1950b) entrapped oil may be expelled.

Fourth, the tendency of certain bacteria to grow on solid surfaces is another mechanism by which adherent oil may be removed from the surface of sedimentary particles. Those that produce detergents are most effective. Bacterially produced detergents and fatty acids both bring about water emulsions of oil that may promote its flow to a structural or stratigraphic trap.

Regardless of the problematical practical applications of the bacterial process to the secondary recovery of oil, bacteria that induce the release and flow of oil are believed to have played an important part in the migration and accumulation of oil throughout the geological ages.

REFERENCES

BACH, and SIERP, *1924*. Untersuchungen über den anaëroben Abbau organischer Stoffe durch Bakterien des Klärschlammes: *Centralbl. f. Bakt.*, Abt. II, vol. 62, pp. 24–76.

BARKER, H. A., *1936*. On the biochemistry of the methane fermentation: *Archiv f. Mikrobiol.*, vol. 7, pp. 404–419.

BASTIN, E. S., *1926*. The problem of the natural reduction of sulphates: *Am. Assoc. Petroleum Geologists Bull.*, vol. 10, pp. 1270–1299.

———, and GREER, F. E., *1930*. Additional data on sulphate-reducing bacteria in soils and waters of Illinois oil fields: *Am. Assoc. Petroleum Geologists Bull.*, vol. 14, pp. 153–159.

BROOKS, B. T., *1936*. Origins of petroleums: Chemical and geochemical aspects: *Am. Assoc. Petroleum Geologists Bull.*, vol. 20, pp. 280–300.

CHIBNALL, A. C., *et al.*, *1934*. The constitution of the primary alcohols, fatty acids, and paraffins present in plant and insects waxes: *Biochem. Jour.*, vol. 28, pp. 2189–2208.

CLARKE, H. T., and MAZUR, A., *1941*. The lipids of diatoms: *Jour. Biol. Chem.*, vol. 141, pp. 283–289.

COX, B. B., *1946*. Transformations of organic material into petroleum under geological conditions (The geological fence): *Am. Assoc. Petroleum Geologists Bull.*, vol. 30, pp. 645–659.

GAHL, R., and ANDERSON, BELLE, *1928*. Sulphate-reducing bacteria in California oil waters: *Centralbl. f. Bakt.*, Abt. II, vol. 73, pp. 331–338.

GINSBURG-KARAGITSCHEVA, T. L., *1933*. Microflora of oil waters and oil-bearing formations and biochemical processes caused by it: *Am. Assoc. Petroleum Geologists Bull.*, vol. 17, pp. 52–65.

GINTER, R. L., *1930*. Causative agents of sulphate reduction in oil-well waters: *Am. Assoc. Petroleum Geologists Bull.*, vol. 14, pp. 139–152.

HACKFORD, J. E., *1932*. Chemistry of conversion of algae into bitumen and petroleum of fucosite-petroleum cycle: *Inst. Petroleum Technologists Bull.*, vol. 18, pp. 74–113.

HONIG, R. E., and SHEPPARD, C. W., *1946*. An experimental comparison of the chemical effects of deuterons and of alpha particles on methane and n-butane: *Jour. Phys. Chem.*, vol. 50, no. 2, pp. 119–143.

JANKOWSKI, G. J., and ZOBELL, C. E., *1944*. Hydrocarbon production by sulfate-reducing bacteria: *Jour. Bact.*, vol. 47, p. 447.

LIND, S. C., *1938*. On the origin of petroleum: *Science of Petroleum*, vol. 1, pp. 39–41.

MALIYANTZ, A. A., *1935*. Bacteriological method of desulphurizing crude: *Azerb. Neft. Khoz.*, vol. 6, pp. 89–93.

MÜLLER, A., *1944*. Researches in the bacteriology of petroleum: Doctorate Dissertation, Technisch Hochschule Karlrule, Baden, 35 pp.

———, and SCHWARTZ, W., *1949*. Untersuchungen zur Erdölbakteriologie I.: *Archiv f. Mikrobiol.*, vol. 14, pp. 291–308.

NEAVE, S. L., and BUSWELL, A. M., *1928*. Treatment and disposal of distillery slop by anaerobic digestion methods: *Ind. and Eng. Chemistry*, vol. 20, pp. 837–838.

NICHOLS, R. I., *1941*. The origin of atmospheric hydrogen: *Amer. Meteorol. Soc. Bull.*, vol. 22, pp. 211–213.

PORTER, J. R., *1946*. *Bacterial chemistry and physiology:* John Wiley and Sons, Inc., New York, 1073 pp.

RAWN, A. M., BANTA, A. P., and POMEROY, R., *1939*. Multiple-stage sewage sludge digestion: *Am. Soc. Civil Eng. Trans.*, vol. 104, pp. 93–132.

RITTENBERG, S. C., *1940*. Bacteriological analysis of some long cores of marine sediments: *Jour. Marine Research*, vol. 3, pp. 191–201.

SANDERS, J. M., *1937*. The microscopical examination of crude petroleum: *Inst. Petroleum Technologists Bull.*, vol. 23, pp. 525–573.

SEYER, W. F., *1933*. Conversion of fatty and waxy substances into petroleum hydrocarbons: *Am. Assoc. Petroleum Geologists Bull.*, vol. 17, pp. 1251–1267.

SISLER, F. D., and ZOBELL, C. E., *1951*. Hydrogen utilization by some marine sulfate-reducing bacteria: *Jour. Bact.*, vol. 62, pp. 117–127.

SKELTON, A. G., and SKELTON, MARTHA B., *1942*. A selective bibliography on the theories of the origin of petroleum: *Oklahoma Geol. Survey, Mineral Report No. 7*, 10 pp.

SMITH, P. V., *1952*. Preliminary note on origin of petroleum: *Am. Assoc. Petroleum Geologists Bull.*, vol. 36, pp. 411–413.

STEPHENSON, MARJORY, *1947*. Some aspects of hydrogen transfer: *Antonie van Leeuwenhoek*, vol. 12, pp. 33–48.

TAUSSON, W. O., and ALESHINA, W. A., *1932*. Über die bakterielle Sulfatreduktion bei Anwesenheit der Kohlenwasserstoffe: *Mikrobiologiia*, vol. 1, pp. 229–261.

———, and SHAPIRO, S. L., *1934*. The general trend of the process of oxidation of oil by bacteria: *Mikrobiologiia*, vol. 3, pp. 79–87.

TAUSZ, J., *1919*. Über die Einwirkung von Microorganismen auf Roherdöle: *Petroleum Zeitschr.*, vol. 15, pp. 553–555.

UPDEGRAFF, D. M., *1948*. The production of phenol and para-cresol by marine bacteria: *Jour. Bact.*, vol. 57, pp. 555–564.

WAKSMAN, S. A., *1933*. On the distribution of organic matter in the sea bottom and the chemical nature and origin of marine humus: *Soil Sci.*, vol. 36, pp. 125–147.

———, *1935*. Chemical nature of organic matter of humus in soils, peat bogs, and composts: *Jour. Chem. Education*, vol. 12, pp. 511–519.
———, *1936. Humus: Origin, chemical composition, and importance in nature:* Williams & Wilkins, Baltimore, 494 pp.
WHITEHEAD, W. L., and BREGER, I. A., *1950*. The origin of petroleum: Effects of low temperature pyrolysis on the organic extract of a recent marine sediment: *Science*, vol. 111, no. 2883, pp. 335–337.
WHITMORE, F. C., *1945*. Studies in the fields of chemistry, bacteriology, physical chemistry, and physics: *Am. Petroleum Inst. Proc.*, vol. 25, no. IV, pp. 100–102.
ZOBELL, C. E., *1938*. Studies on the bacterial flora of marine bottom sediments: *Jour. Sedimentary Petrology*, vol. 8, pp. 10–18.
———, *1942*. Changes produced by microorganisms in sediments after deposition: *Jour. Sedimentary Petrology*, vol. 12, pp. 127–136.
———, *1943*. Influence of bacterial activity on source sediments: *Oil Weekly*, vol. 109, pp. 15–26.
———, *1946a*. Studies on redox potential of marine sediments: *Am. Assoc. Petroleum Geologists Bull.*, vol. 30, pp. 477–513.
———, *1946b*. Action of microorganisms on hydrocarbons: *Bact. Rev.*, vol. 10, pp. 1–49.
———, *1947a*. Bacterial release of oil from oil-bearing materials: *World Oil*, vol. 126, no. 13, pp. 36–47, and vol. 127, no. 1, pp. 35–41.
———, *1947b*. Microbial transformation of molecular hydrogen in marine sediments, with particular reference to petroleum: *Am. Assoc. Petroleum Geologists Bull.*, vol. 31, pp. 1709–1751.
———, *1950*. Assimilation of hydrocarbons by microorganisms: *Advances in Enzymology*, vol. 10, pp. 443–486.
———, *1950b*. Bacterial activities and the origin of oil: *World Oil*, vol. 130, no. 7, pp. 128–138.
———, and ANDERSON, D. Q., *1936*. Vertical distribution of bacteria in marine sediments: *Am. Assoc. Petroleum Geologists Bull.*, vol. 20, pp. 258–269.
———, and JOHNSON, F. H., *1949*. The influence of hydrostatic pressure on the growth and viability of terrestrial and marine bacteria: *Jour. Bact.*, vol. 57, pp. 179–189.
———, and RITTENBERG, S. C., *1948*. Sulfate reducing bacteria in marine sediments: *Jour. Marine Research*, vol. 7, pp. 602–617.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 50–52
MARCH, 1952

DISCUSSION

LOESS, AN EOLIAN PRODUCT

Correction and a reply to the remarks of F. F. F. E. van Rummelen

D. J. DOEGLAS
Agricultural University, Wageningen, Netherlands

In the author's paper on the origin of loess in the *Journal of Sedimentary Petrology* of December 1949 a regrettable error has been made. According to table I the epidote percentage of the Oligocene was zero and that of garnet only 3 per cent. The author used mineral data from the continental Oligocene in N.E. Belgium. In the Dutch South Limburg, however, the Oligocene is marine and contains an average of 12 per cent epidote and 14 per cent garnet. The other Tertiary formations in this area are continental and are practically free of epidote.

In December 1950 F. F. F. E. van Rummelen discussed this error in a Dutch popular scientific paper and in the March, 1951 number of the *Journal of Sedimentary Petrology* a translation of this paper appeared. The tables I and II of these papers by van Rummelen not only show epidote in the Oligocene but also in the other Tertiary series of South Limburg. As van Rummelen referred to a large number of his own analyses, present already in manuscript form, the author waited to answer him until this paper appeared.

The second paper of van Rummelen (1951), however, forces the author not only to correct his error but also to prove that the average epidote percentages given by van Rummelen give a wrong impression of the mineral associations of the Cretaceous, Miocene and Pliocene.

The percentages in the author's paper of 1949 had been estimated. In the present paper (table 1) the percentages of garnet, hornblende and epidote have been calculated. The number of samples used for these calculations have been indicated and the authors from which the data have been taken are mentioned. The mineral tables in the papers used are indicated in the bibliography. The percentages of epidote given by van Rummelen and by the author in 1949 are given too.

The average percentages of epidote calculated by the author and those given by him in 1949 only deviate for the Oligocene and a thin basal layer of the Middle Miocene which according to Mueller (1943) consists of reworked marine Oligocene. The discrepancies between the average percentages of epidote of van Rummelen and those calculated by the author, however, are large except for the Oligocene. The number of data used has no influence: van Rummelen 751—Doeglas 566.

When the percentage of epidote of the loess is compared with those calculated by the author for the underlying formations, it is clear that only the base of the Middle Miocene and the Oligocene could have contributed epidote to the loess. The average percentage of epidote in these formations, however, is about half that of the loess.

The percentage of hornblende gives a more striking difference. The loess contains an average of 7.2 per cent and the average percentage of the underlying formations is less than 0.1. Only the Pleistocene terraces contain a high hornblende percentage. The hornblende variety in the terraces, however, is brown green and that of the loess blue green.

The garnet of the loess (average 16 per cent) also could have been derived from the basal Miocene and the Oligo-

TABLE 1

	Doeglas, 1951				v. Rummelen 1951		Doeglas 1949
	Number of samples	Garnet	Hornblende	Epidote	Epidote	Number of samples	Epido
Loess (Edelman)	16	16	5.0	24.0			
Loess (Doormaal)	36	16	8.2	28.7			
Loess—average	(52)	16	7.2	27.3			
van Baren, Zonneveld							
Middle terrace	39	1.4	27.0[1]	3.6[2]			3
Upper terrace	213	1.4	11.4[1]	2.3[2]			
Muller							
Pliocene							
Kiezeloölite terrace	49	2.4	0.04[3]	1.1	2[4]	421	2
Upper Miocene	0				22	11	
Middle Miocene							
garnet-free zone	34	0.7	0.0	0.1			
garnet-rich zone	48	19.5	0.04	0.12	6.6	48	0
basal marine zone	15	27.4	0.6	9.3[5]			
Upper Oligocene	24	22.2	0.04	15.4	14	60	
Middle Oligocene	136	12.4	0.02	9.0	9	162	
Lower Oligocene	49	17.2	0.18	17.2	24	48	
Total Oligocene	(209)	14.0	0.06	12.0	12.8	(270)	0
Senonian, S. Limburg	39	3.9	0.0	0.25	14	1	0
Senonian, E. Brabant	72	3.5	0.0	0.04			
Edelman-Doeglas							
Pliocene	9	1.3	0.0	0.1			
Miocene	5	0.6	0.0	0.0			
Upper Oligocene	12	5.0	0.0	4.6			
Middle Oligocene	66	15.4	0.15	2.3			
Lower Oligocene	8	10.7	0.4	8.5			

[1] Hornblende in Pleistocene terraces is brown-green, in loess blue-green.
[2] Includes saussurite.
[3] Muller did not analyse samples from Upper Miocene.
[4] van Rummelen calculated 5 per cent epidote. According to his own table I it is only 2 per cent.
[5] The garnet- and garnet-free zones are 60–100 meters thick, the marine base of the Middle Miocene is 10–20 meters and represents reworked Oligocene according to Muller. Lower Miocene is absent.

cene. In the southern part of South Limburg and in Belgium the Miocene is absent and the Oligocene only occurs in small patches. The loess overlies the Senonian or Pleistocene terraces.

The Senonian of South Limburg (39 well samples) and of areas farther North investigated by Muller (1943), a total of 111 well samples, contains less than 0.25 per cent epidote. Van Rummelen gives only one sample with 14 per cent epidote, analyzed by himself.

The basis of the author's paper on the eolian origin of the loess minerals, there-

fore, has not been weakened. The mineral association of the loess in South Limburg could not have been derived from the underlying formations and as it is very similar to the mineral association of the glacial deposits in the central part of the Netherlands an eolian transport is necessary.

REFERENCES

BAREN, F. A. VAN, *1934*. Het voorkomen en de beteekenis van kalihoudende mineralen in Nederlandsche gronden: Thesis, Wageningen, Netherlands, tables V and VI.

DOEGLAS, D. J., *1949*. Loess, an eolian product: *Jour. Sedimentary Petrology*, vol. 19, pp. 112–117.

DOORMAAL, J. C. A. VAN, *1945*. Onderzoekingen betreffende de loessgronden van Zuid-Limburg: Thesis, Wageningen, 88 pp.

EDELMAN, C. H., *1933*. Petrologische Provincies in het Nederlandsche Kwartair, Thesis, Amsterdam, table XXIII.

EDELMAN, C. H., and DOEGLAS, D. J., *1933*. Bijdrage tot de petrologie van het Nederlandsche Tertiair: *Verhandelingen Geologisch-Mijnbouwk.* Genootschap, 10, 1, pp. 1–38, tables IVb, Va–b and VI.

MULLER, J. E., *1943*. Sediment-petrologie van het dekgebergte in Limburg: *Mededelingen Geologische Stichting*, serie C-II-2-2, tables II, VII–XV, XVII, XVIII.

RUMMELEN, F. F. F. E. VAN, *1950*. Enige opmerkingen omtrent het mineraal epidoot naar aanleiding van het loessprobleem: Natuurhistorisch Maandblad, 39, 12, pp. 139–140.

RUMMELEN, F. F. F. E. VAN, *1951*. Some remarks on the mineral epidote in connection with the loess problem: *Jour. Sedimentary Petrology*, vol. 21, pp. 183–184.

RUMMELEN, F. H. VAN, *1950*. Erratica in de loessoïden van Ransdaal (met medewerking van F. F. F. E. van Rummelen): *Natuur-Hittorisch Maandblad*, 39, 5–8.

ZONNEVELD, J. I. S., *1949*. Zand-petrologische onderzoekingen in de terrassen van Zuid-Limburg: *Mededelingen van de Geologische Stichting*, no. 3, pp. 103–123.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, P. 53
MARCH, 1952

REPLY TO THE REMARKS OF N. M. SHUKRI ON "BEACH SANDS OF THE MEDITERRANEAN COAST OF EGYPT" BY M. E. HILMY

MOHAMED E. HILMY
Farouk I University, Alexandria, Egypt

In reply to Dr. Shukri's "Remarks on 'Beach Sands of the Mediterranean Coast of Egypt'—" which appeared in the September 1951 issue of the *Journal*, and which referred to my paper in the June, 1951, issue of the *Journal*, I wish to point out that "previous" publication on the black sands at Rosetta occurred in the October 1950 issue of the Quarterly Journal of the Geological Society of London, and that this issue was received by the University of Michigan libraries on November 27, 1950. By this time I had finished my paper, most of the work on it having been done before I came to the United States in 1948. My paper was received by the *Journal of Sedimentary Petrology* on December 18, 1950.

Dr. Davidson wrote on September 11, 1951, drawing my attention to his addendum on Shukri's paper, and I first read Shukri's paper, entitled "The Mineralogy of some Nile Sediments," in September, 1951. The surprising thing is that out of 150 samples described, there is only one sample collected from Rosetta on the Mediterranean beach. Of this one sample Dr. Shukri says (op. cit. p. 522): "The sand examined from Rosetta (locality 52) is a black beach sand, worked for monazite in places, and is different from the typical Nile sediments. It is poor in both pyroxenes and amphiboles and rich in augite relatively to hornblende. This is due to the sorting action of waves along the beach." Besides showing the location of Rosetta on the map (op. cit. pl. XXX), that was all that was contributed by Dr. Shukri to the sedimentology of the beach sands of the Mediterranean Coast of Egypt. The contribution of Dr. Davidson in the discussion of Shukri's paper (Quart. Jour. Geol. Soc. London, *cv*, pp. 533–534) is of real interest with regard to the black sands of the Mediterranean beach of Egypt, but unfortunately, as I mentioned above, I was not aware of its publication at the time I had finished my paper.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 54–55
MARCH, 1952

REVIEW

The Tectonics of Middle North America: Middle North America East of the Cordilleran System by Philip B. King. Princeton University Press, Princeton, N. J., 1951. Pp. XIX–203, frontispiece and 50 figures. $3.75.

Geologists were indebted to Dr. King for the able summary of the structural geology of the United States which appeared in 1933 for the 16th International Geological Congress, but the appearance of this book 18 years later increases their indebtedness. About two-thirds of the North American continent is considered, the Cordillera being excluded. The comparison of the old and new versions is illuminating as it gives a measure of the advance made in the last two decades in a part of the world where geological activity has been particularly vigorous and geologists peculiarly favored because of the enormous amount of new evidence made available by drilling. The author deserves special gratitude for bringing much of this that is pertinent into focus with a judicious suppression of almost all the bewildering place names that sometimes blight accounts of stratigraphy. The familiar divisions appear as a Central Stable Region, a belt of Paleozoic Mountain Structures, and the Coastal Plains.

The central stable region is broken up into the Laurentian Shield forming much of Canada and two lobes reaching the northern part of the United States and into a broad belt of Interior Lowlands. It is shown that the shield although acting as an entity since Cambrian times is diverse in its structure. A very ancient part, some 2000 million years old, has been identified and its sediments persist unaltered, showing hardly any metamorphism, whilst a much younger series about half the age occurs in a state of intense alteration. The interior lowlands which are occupied by the unaltered and only slightly deformed Paleozoic formations of the veneer are dealt with in two parts, that of the basins and uplifts in the one hand and of the foreland in the other. The uplifts of Wisconsin, the Ozarks, Cincinnati, and Nashville are described much as they were in 1933, but the information regarding the thick and varied sediments within the basins has accumulated enormously, and several new basins have been discovered. Dr. King makes a point of recognizing a foreland along the south eastern edge of the interior lowlands in which the sediments thicken towards a geo-synclinal area and writes of a hinge line between it and the geosyncline. This is hypothetical rather than actual to judge by the illustrations.

The Paleozoic structures aligned from Newfoundland to Alabama constitute the Appalachian chain. In a discussion of this region it appears that elements of Taconic, Acadian, and Appalachian orogenes can be distinguished, clearly in some parts, obscurely in others, and may be reasonably inferred elsewhere, and the rocks occur in distinct belts where metamorphism is negligible, considerable and intense respectively. Concordant batholiths or injection complexes have been recognized and there are besides discrete discordant granites with narrow aureoles of contact metamorphism. Comparison between the northwesterly "Valley and Ridge" province of the Central Appalachians and the Jura Mountains has often been made. It is interesting to compare King's (fig. 32) diagram with Buxtorf's from which it emerges that the idea of decollement and movement over a lubricant is common to both. The eastern part of fig. 32 which does not appear in the original paper by Rodgers implies the conception of nappes de recouvrement which are not explicitly described in the text, but the profile raises intriguing possibilities. Can it be that the cult of nappes sliding downhill, the idea of "écoulement" which is

now flourishing in France, Switzerland, and Holland has found an apostle in North America? The tightly folded and intruded central region and the marginal zone of low angle thrusts and imbrication recall the pattern of the Alps insistently. The reviewer was surprised to find no mention of the salt tectonics of Nova Scotia.

The subdivision of the book which describes the structures west of the Mississippi River copes with structures imperfectly displayed but marshals the material to make it clear that a mountain chain lies buried here which rose at different times in the Appalachian orogeny. The later formed Ouachita part of the system abuts against the edge of the earlier folded Wichita section much as the middle-east Alpine structures do against the Bergamasc zone in Italy (L. U. deSitter, Geol. en Mijn, 9, pp. 1–13, 1947). The author stimulates speculation about the missing link between the Southern Appalachians and the eastern Ouachita Mountains. The change in facies involved is a difficulty, but at least at one place in the Iranian ranges known to the reviewer, a sudden change in facies takes place with a deflection such as may be postulated as one possibility occurring below the Cretaceous of the Mississippian embayment. The problem set by the boulder beds shown in fig. 42 which the author seeks to solve as a fossil landslip is another fascinating one. Such beds are found in Baluchistan and India as well as in Italy and some of these are explained as due to the rupturing of sturdier beds, and the carriage of the fragments in a softer rock like shale which has been induced to flow, much as a plum stone may be squeezed out of a ripe fruit.

The coastal plains form a unit which is unsatisfactory tectonically but the heading serves geographically for the discussion of a heterogeneous province in which structures are superficially simple even if complex at depth. The growth of knowledge about the shape of the packets of strata in this strip has been rapid and the detection of a large syncline parallel to the coast raises a comment from the author that an incipient geosyncline may be growing here. The uplifts, basins, faults, and salt-plugs of the western part receive reasonable treatment. The most baffling of the phenomena set forth is a group of faults which increase in throw down-wards; have facies change across them; and show drag-folding in the wrong sense, vide fig. 49. These occur in young strata with a tilt seawards which is vaguely reminiscent of the Pacific coast in Ecuador and Peru where bedding-plane faults and transcurrent faults occur. Such fractures, if envisaged here, would tend to remove some of the apparent difficulties.

Finally no review would be adequate which did not refer to the newly drawn diagrams in which the uniformity of a constant exaggeration of vertical scale makes comparison between them all possible. It is to be hoped that when the second part of the book appears some map of the type that accompanied the 1933 Guide Book will be provided, because although many maps are recommended in the bibliography, an ad hoc map greatly facilitates the reading of the book and provides for the implications of the saying that "all men are indolent."

J. V. HARRISON, OXFORD, ENGLAND
Visiting Professor
University of Illinois

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 22, NO. 1, PP. 56–57
MARCH, 1952

ANNOUNCEMENTS

CORDILLERAN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA MEETING
April 11 and 12, 1952

The program for the forty-eighth annual meeting of the Cordilleran Section of the Geological Society of America to be held in Tucson, Arizona on the University of Arizona campus on April 11 and 12, 1952, has been announced by Prof. Edwin D. McKee, Chairman of the program committee and professor of geology of the University of Arizona.

"Ninety-eight papers will be presented," says Prof. McKee. "This represents over fifty per cent more papers than were given at the last meeting of this group." Included will be twenty-one papers on seismology and eleven papers dealing with the geology of Arizona.

Members of the committee preparing the program were Prof. McKee, chairman, Dr. V. L. VanderHoof, secretary of the Cordilleran Section and Professor of vertebrate paleontology, Stanford University, Palo Alto, California, Dr. Charles A. Anderson, United States Geological Survey, Prescott, Arizona, and Mason L. Hill, Richfield Oil Corporation, Los Angeles, California.

This meeting is sponsored by the Arizona Geological Society, Tucson.

Outstanding in the program is a panel discussion of mountain building to be conducted Friday, April 11, by Dr. H. N. Fiske, Humble Oil Company, Los Angeles, California, Dr. William H. Easton, University of Southern California, Los Angeles, California, Drs. Francis J. Turner and Jean Verhoogen, University of California at Berkeley, California, Dr. Hugo Benioff, California Institute of Technology, Pasadena, California, and Dr. James Gilluly, United States Geological Survey, Denver, Dr. Ian Campbell of the California Institute of Technology will be the moderator.

Of special interest to students will be a panel discussion of employment opportunities. Members of the panel will be representatives of commercial, institutional and governmental agencies.

Concurrent with general meeting of the Cordilleran Section will be meetings of the Seismological Society of America, the Paleontological Society of America and the Mineralogical Society of America.

Four concurrent one-day field trips will be conducted on Thursday, April 10 before the meeting. Some aspects of ground water, stratigraphy, metamorphism and economic geology in Arizona will be presented in the four trips.

The ground-water trip will be through the Queen Creek and Santa Cruz River basins and will be conducted by Samuel F. Turner and Leonard O. Halpenny, United States Geological Survey, Tucson.

The stratigraphic trip will be reconnaissance of an area of Paleozoic and Cretaceous sections near Tucson, conducted by Prof. Donald L. Bryant and Dr. John F. Lance, University of Arizona, Tucson. The trip to a metamorphic area will be conducted in the Santa Catalina Mountains by Dr. Bert S. Butler, University of Arizona and Calvin S. Bromfield, United States Geological Survey, Tucson.

The economic geology trip will be to the Ajo mining district west of Tucson. It will be conducted by Dr. Andrew F. Shride, of the United States Geological Survey, Tucson.

Following the meeting there will be a two-day field trip through central Arizona conducted by Dr. Eldred D. Wilson, Arizona Bureau of Mines, Dr. George A. Kiersch, University of Arizona and Drs. John W. Harshbarger and Andrew F. Shride, United States Geological Survey.

The two-day trip will traverse a cross section of southern Arizona from the basin-range country, northward through the mountain area to the Colorado Plateau. Stops along the way include the

new San Manual copper area, Ray, Superior, Miami-Globe and the Salt River Canyon. The new open-pits at Inspiration-Miami and the Castle Dome District will be visited.

A general banquet will be held Friday evening at 7 P.M. and special and business meeting luncheons will be held by various groups during the two days.

Entertainment for ladies will include an excursion to San Xavier Mission and other features in the Tucson area and a luncheon and style show will be held Saturday, April 12.

A wide variety of professional, commercial and local exhibits will be displayed.

GUIDEBOOK FOR THE FORTY-EIGHTH MEETING, CORDILLERAN SECTION, GEOLOGICAL SOCIETY OF AMERICA

The contents of the guidebook for the field trips to be held in conjunction with the April, 1952 meeting of the Cordilleran Section of the Geological Society of American have been announced by the Arizona Geological Society, sponsor of the meetings. This guidebook will be the first publication on the general geology of southern Arizona since 1925. Included will be detailed road logs of five trips and fifteen articles.

In connection with the four concurrent one-day pre-meeting trips to be offered, the following topics are discussed in the guidebook: ground-water problems, especially those of recharge, in the irrigated desert area east of Phoenix; typical Paleozoic and Cretaceous stratigraphy of the Tucson Mountains immediately west of Tucson; some metamorphic features, possibly relevant to the granitization problem, exposed in the Santa Catalina Mountains immediately north of Tucson; and the geology of the New Cornelia copper mine at Ajo.

The two-day post-meeting trip will traverse a cross section of Arizona from the basin-range province, northward through the mountain area to the Colorado Plateau. Papers describe the mining areas of San Manuel, Ray, Superior, Castle Dome, and the Globe-Miami district; structure and stratigraphy of the Winkelman-Ray, Ray-Superior, and Globe-Miami areas; the Gila conglomerate problem; the diabase problem of north-central Arizona; and the upper Paleozoic stratigraphy of the southern border of the Colorado Plateau.

Papers included in the guidebook are as follows:

L. C. Halpenny and S. F. Turner, "Ground-Water Problems of the Queen Creek Area"

H. N. Babcock and E. M. Cushing, "Recharge to Ground Water from Floods in a Typical Desert Wash, Pinal County, Arizona"

D. L. Bryant and J. F. Lance, "Paleozoic and Cretaceous Stratigraphy of Tucson Mountains"

C. S. Bromfield, "Some Geological Features of the Santa Catalina Mountains"

H. W. Steele, "San Manuel Copper Deposit"

G. A. Kiersch, "Geology of the Hayden Area"

O. S. Clarke, Jr., "Structural Control of Ore Deposition at Ray, Arizona"

E. D. Wilson, "General Geology between Ray and Superior, Arizona"

H. W. Steele, "Geology and Ore Deposits of Magma Mine"

L. A. Heindl, "Gila Conglomerate"

N. P. Peterson, "Structural History of the Globe-Miami District"

N. P. Peterson, "Castle Dome Copper Deposit"

A. F. Shride, "Geology of Salt River Canyon in Vicinity of Highway 60"

R. L. Jackson, "Penn-Permian Facies of the Supai Formation in Central Arizona"

The geology of the New Cornelia Mine, Ajo, Arizona, will be described.

Teaching Aids for Optical Mineralogy

Interference Figures of Crystals Under Polarized Light. A set of 41 color slides illustrating uniaxial and biaxial interference figures, determination of positive and negative figures and sections normal to an optic axis. **LX 25** Complete set of 41 slides with script, postpaid **$30.75**

Grain-Thin-Sections. A new development whereby one slide will possess several grains illustrating the complete optical character of the mineral.

Multiple Oriented Sections. 4 new slides: *Interference Figures, Relief Scale, 2 V Slide, Bxa-Bxo Slide.* Complete set of 40 grain-thin-sections plus 4 multiple oriented sections .....**$110.00** (list Roch. N.Y.)

GEOLOGICAL SUPPLIES AND EQUIPMENT. Ward's outstanding equipment service is organized to meet the special requirements of the geologist, mineralogist, and paleontologist. Simplify your procurement problem by writing for free illustrated price list . . . "Supplies for the Geologist."

WARD'S NATURAL SCIENCE ESTABLISHMENT, INC.

3000 RIDGE ROAD EAST • ROCHESTER 9, N.Y.

THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

P.O. Box 979, Tulsa 1, Oklahoma

Published *annual volumes* of the S.E.P.M. are available at the following terms.

		Regular Price Per. Vol.	Special to Members Per. Vol.
JOURNAL OF PALEONTOLOGY:			
Vol. 1 (1927).	Complete in 4 Nos. Reprinted 1948		
	Paper-bound copies	$ 6.00	$ ——
	Cloth-bound copies	6.50	——
Vol. 2 (1928).	Complete in 4 Nos.	8.00	6.00
Vol. 3 (1929).	Only Nos. 1 and 2 Available	4.00	3.00
Vol. 4 (1930).	Only Supplement 1 Available	2.00	1.50
Vols. 5 to 8 (1931-34).	Each Complete in 4 Nos.	8.00	6.00
Vols. 9 to 11 (1935-37).	Each Complete in 8 Nos.	16.00	12.00
Vols. 12 to 22 (1938-48).	Each Complete in 6 Nos.	12.00	9.00
Vol. 23 (1949).	Only Nos. 3 to 6 Available	8.00	6.00
Vol. 24 (1950).	Only Nos. 2 to 6 Available	10.00	7.50
Vol. 25 (1951).	Complete in 6 Nos.	12.00	9.00
Vol. 26 (1952).	Non-member, $10.00; Outside U.S., $10.40. Member, Covered by $6.00 dues, postpaid.		
SINGLE ISSUES:	Non-Members, $2.00; Members, $1.50.		
JOURNAL OF SEDIMENTARY PETROLOGY:			
Vol. 1 (1931).	Only No. 1 Available	$ 1.75	$ 1.35
Vols. 2 to 7 (1932-37).	Each Complete in 3 Nos.	5.25	4.05
Vol. 9 (1939).	Only No. 1 Available	1.75	1.35
Vol. 12 (1942).	Complete in 3 Nos.	5.25	4.05
Vol. 13 (1943).	Only Nos. 1 and 2 Available	3.50	2.70
Vol. 15 (1945).	Only No. 1 Available	1.75	1.35
Vol. 17 (1947).	Only Nos. 1 and 2 Available	3.50	2.70
Vol. 18 (1948).	Only Nos. 2 and 3 Available	3.50	2.70
Vol. 19 (1949).	Complete in 3 Nos.	5.25	4.05
Vols. 20 and 21 (1950-51).	Each Complete in 4 Nos.	7.00	5.40
Vol. 22 (1952).	Non-member, $5.00; Outside U.S. $5.40. Member, Covered by $4.00 dues, postpaid.		
SINGLE ISSUES:	Non-members, $1.75; Members, $1.35.		

BIBLIOGRAPHY OF OTOLITHS, by Robert B. Campbell, 32 pp. (Sept., 1929) .....$1.00 per copy

TURBIDITY CURRENTS AND THE TRANSPORTATION OF COARSE SEDIMENTS TO DEEP WATER, A Symposium, 107 pp. (Nov., 1951) .....Non-members, $2.75 per copy
Members, $2.25 per copy

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

SOCIETY OFFICERS (MARCH 1952-MARCH 1953)

President: CLIFFORD C. CHURCH, San Francisco, California

First Past-President: THOMAS H. PHILPOTT, Shreveport, Louisiana

Second Past-President: WILLIAM C. KRUMBEIN, Evanston, Illinois

Vice-President: MORTON B. STEPHENSON, Houston, Texas

Secretary-Treasurer: CECIL G. LALICKER, Dept. of Geology, University of Kansas, Lawrence, Kansas

Editor, Journal of Sedimentary Petrology: J. L. HOUGH, University of Illinois, Urbana, Illinois

Editors, Journal of Paleontology: GROVER MURRAY and LOUIS J. WILBERT, Louisiana State University, Baton Rouge, Louisiana

PACIFIC SECTION OFFICERS (1951-1952)

President: W. T. ROTHWELL, Long Beach, California

Secretary-Treasurer: JAMES L. COWELL, Ventura, California

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

ASSOCIATION OFFICERS (MARCH 1952-MARCH 1953)

President: MORGAN J. DAVIS, Houston, Texas

Past-President: FRANK A. MORGAN, Los Angeles, California

Vice-President: JOHN G. BARTRAM, Tulsa, Oklahoma

Secretary-Treasurer: ROBERT H. DOTT, Oklahoma Geological Survey, Norman, Oklahoma

Editor: KENNETH K. LANDES, Ann Arbor, Michigan

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN